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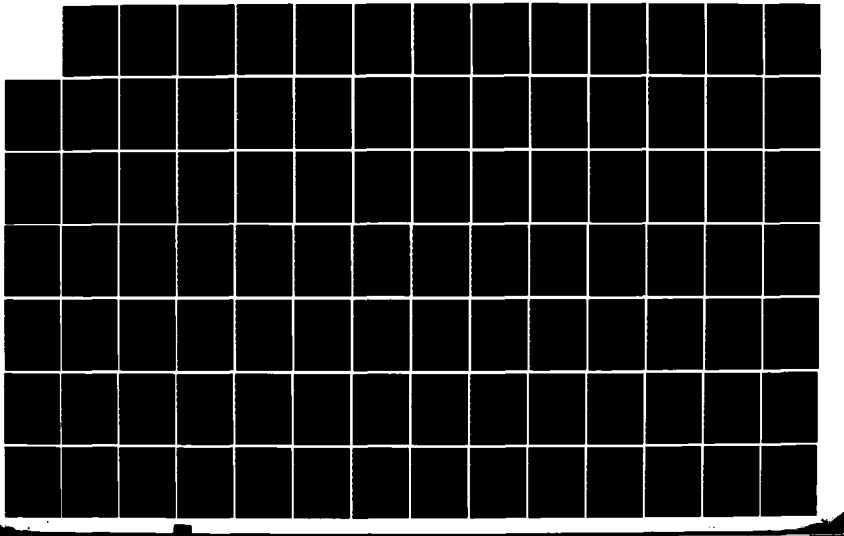

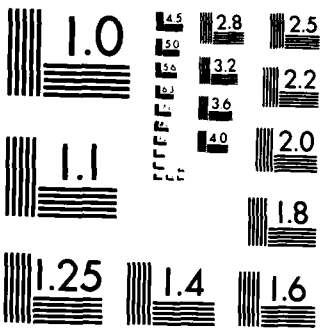

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MICRO-COMPUTER PROCESSING OF LANDSAT THEMATIC MAPPER DATA FOR THE ACQUISITION OF MILITARY TACTICAL TERRAIN DATA

STEPHEN J. MCGREGOR
Captain O-3
HQDA, MILPERCEN (DAPC-OPA-E)
200 Stovall Street
Alexandria, VA 22332

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This study demonstrates the potential use of microcomputer image processing techniques for obtaining tactical terrain data from LANDSAT multispectral digital imagery. Militarily significant land cover classes were mapped for three North Carolina study areas using a modified USGS land cover classification system, LANDSAT Thematic Mapper data, and the Personal Image Processing System (MICROIPS). A site specific accuracy assessment technique, using a stratified, systematic, unaligned sampling design, was

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MICROCOMPUTER PROCESSING OF LANDSAT THEMATIC MAPPER DATA FOR THE ACQUISITION OF MILITARY TACTICAL TERRAIN DATA

by

Stephen J. McGregor

A Thesis submitted to the faculty of The University of North Carolina at Chapel Hill in partial fulfillment of the requirements for the degree of Master of Arts in the Department of Geography.

Chapel Hill

1985

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ABSTRACT

STEPHEN J. McGREGOR. Microcomputer Processing of LANDSAT Thematic Mapper Data for the Acquisition of Military Tactical Terrain Data (under the direction of Richard J. Kopec).

This ~~study~~ demonstrates the potential use of microcomputer image processing techniques for obtaining tactical terrain data from LANDSAT multispectral digital imagery. Militarily significant Level I and II land cover classes were mapped for three North Carolina study areas using a modified USGS land cover classification system, LANDSAT 4 Thematic Mapper data, and the Personal Image Processing System (APPLEPIPS).

A site specific accuracy assessment technique, using a stratified, systematic, unaligned sampling design, was used to determine the classification accuracy of the three land cover maps. The classification accuracy was determined to meet the USGS minimum acceptable standard of 85 percent at the 0.05 confidence level.

ACKNOWLEDGEMENTS

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First, I would like to thank my adviser, Dr. Richard J. Kopec, for his encouragement and support which made this project possible. I am also indebted to Chad Mullis, US Army Engineer Topographics Laboratories, for providing the the LANDSAT TM data; and to David R. Easterling and Emma Beckham, for their help and suggestions which made the completion of this study a reality.

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Chapter I

INTRODUCTION

1.1 THE LANDSAT SYSTEM

On July 23, 1972, ERTS-1 was launched into a circular, sun-synchronous orbit at a nominal altitude of 913 km, providing, for the first time, a remote sensing system on a space platform completely dedicated to the acquisition of timely, accurate, and reliable earth resource data. The Earth Resources Technology Satellite System, renamed LANDSAT, provides earth resource data acquisition, processing, and distribution for global resource examination and management. Nearly a dozen nations worldwide receive and process data directly from the LANDSAT remote sensors. Over 100 nations have applied LANDSAT data for indigenous resource development and management. LANDSAT data have been used in the United States to provide resource managers and planners with up-to-date land cover information necessary for effective planning and policy making at the local, state, and national levels. Additionally, numerous multidisciplinary application projects have been completed by private, academic, and governmental research agencies in the areas of agriculture, mineral and petroleum exploration, land use management, water resource management, and forestry, to name but a few.

One application, currently under consideration, is the use of LANDSAT digital imagery in the military planning process. This research project addresses the potential contribution of LANDSAT data to military geography, the military terrain analysis process, and to the military planning process. Additionally, the utility of microcomputer processing of LANDSAT data for the acquisition of tactical terrain data will be demonstrated through the mapping of militarily significant land cover classes in three North Carolina Piedmont study areas using a microcomputer digital image processing system.

1.2 MILITARY GEOGRAPHY AND TERRAIN ANALYSIS

Military geography is defined as the application of the geographic discipline to military affairs. Its primary focus is on the geometry of military situations (the positions and movements of forces and their relationships to objectives, obstacles, and channels of movement) and the effect of location, characteristics, and distributions of environments, peoples, forces, and resources upon military activities and command decisions.[1] The net effect of place and the geometry of situations are evaluated primarily with relation to matters of strategy, tactics, and logistics.

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[1] Pattison,W.D. and Searcy,G.E. Military Geography. Princeton,N.J.: D. van Nostrand Co. Inc. 1960, pp.7.

spectral signature. Spectral signatures are sets of measurements (DN'S) corresponding to a specific land cover type or surface feature on a particular set of multispectral data.[16]

The analysis and classification of LANDSAT 1-5 MSS data in numerous multi-disciplinary application projects clearly demonstrated the feasibility of obtaining accurate land cover information from LANDSAT multispectral digital data.[17] The preliminary evaluation of the LANDSAT 4 TM data, with its improved spectral, spatial, temporal, and radiometric resolution, indicated a significant improvement in the classification accuracy of the land cover categories evaluated using TM data verses MSS data.[18]

The categories or land cover classes most often used in land cover mapping projects are those of the United States Geological Survey's (USGS) Land Use and Land Cover Classification System (see Table 2).[19]

---

[16] Hoffer, R.M. "Bio-Physical Considerations in Applying Computer Aided Analysis Techniques to Remote Sensor Data", Remote Sensing: The Quantitative Approach. NY: McGraw-H Inc. 1978, pp271.

[17] Lindenlaub, J.C. et al. "Applying the Quantitative Approach", Ibid. Chap.6, pp.309-314.

[18] Mattocni, P.A. et al. "An Initial Analysis of LANDSAT 4 TM Data for the Classification of Agricultural, Forested Wetland, and Urban Land Covers", NASA Report No. 215. NSTL Station, MS: Earth Resources Lab, Nov 1982.

[19] Anderson, J.R. A Land Use and Land Cover Classification System for Use With Remote Sensor Data. USGS Professional Paper 964. Washington, DC: US Government Printing Office, 1976.

TABLE 1

Comparison of LANDSAT MSS and TM Sensors

LANDSAT 1-3 MSS			LANDSAT 4-5 TM		
SPECTRAL RESOLUTION					
BAND	WAVELENGTH	RANGE	BAND	WAVELENGTH	RANGE
1	0.50-0.60	Green	1	0.45-0.52	Blue
2	0.60-0.70	Red	2	0.52-0.60	Green
3	0.70-0.80	Near IR	3	0.63-0.69	Red
4	0.80-1.10	Near IR	4	0.76-0.90	Near IR
*5	10.4-12.6	Thermal IR	5	1.55-1.75	Middle IR
			6	10.4-12.5	Thermal IR
* LANDSAT 3 only			7	2.08-2.35	Middle IR
SPATIAL RESOLUTION					
BAND	IFOV	SCENE SIZE ALT	BAND	IFOV	SCENE SIZE ALT
1-4	79x79m	185x185km 915km	1-5,7	30x30m	185x170km 705km
*5	238x238m		6	120x120m	
TEMPORAL RESOLUTION					
REPEAT COVERAGE	ORBIT	#/DAY	REPEAT COVERAGE	ORBIT	#/DAY
18 Days	103min	14	16 Days	99min	14
RADIOMETRIC RESOLUTION					
BAND	#BITS	DN'S SCAN LINES PER SWEEP	BAND	#BITS	DN'S SCAN LINES PER SWEEP
1-3	6	0-127 6	1-5,7	8	0-255 16
4	6	0-63 6	6	8	0-255 4

Regions possessing uniform land cover types are classified based on the parametric approach to land evaluation. The attribute value or parameter used for the classification is the characteristic spectral response pattern of

straints, accessibility, and the need for surprise and secrecy. A potential alternative source of tactical terrain data, currently under consideration, is the multispectral digital imagery from the LANDSAT 4 and 5 earth resource satellite's Thematic Mapper (TM) scanner.

The Earth Resource Technology Satellite (ERTS) system, renamed LANDSAT, was initiated in the 1970's to provide resource managers and planners with up-to-date land cover information necessary for effective planning and policy making at the local, state, and national levels. Land cover information is provided in the form of land cover and/or land use maps derived from the computer processing of multispectral digital data, recorded and transmitted by the LANDSAT's mechanical scanning radiometer. This remote sensing device records the average spectral reflectance of all earth surface materials, within the instantaneous field of view (IFOV) of the scanner, as a discrete integer value or digital number (DN) for each of several visible and infrared wavelength bands of the electromagnetic spectrum. Table 1 compares the resolution of the LANDSAT multispectral scanner (MSS), the primary sensor on LANDSAT 1-3, and the Thematic Mapper (TM) on LANDSAT 4[14] and 5.[15]

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[14] Short, N.M. The LANDSAT Tutorial Workbook: Basics of Satellite Remote Sensing. NASA Reference Publication 1078. Washington, DC: NASA Scientific and Technical Information Branch, 1982, pp. 409-419.

[15] LANDSAT 4 Data Users Handbook. Washington, DC: USGS, 1984, pp. 4-1.

intensive personal reconnaissance of the terrain."[13] The size of potential battlefields of the Twentieth century and beyond makes this personal reconnaissance impractical if not impossible. Commanders of forward deployed units in Europe, Asia, and Latin America possess this capability to a certain extent. However, commanders in the United States' Rapid Deployment Force (RDF) must rely heavily on topographic maps, aerial imagery, and the previously mentioned ancillary references for this reconnaissance and the acquistion of terrain data.

The increasing reliance on maps and aerial imagery in the terrain analysis process has made the impact of erroneous or out-of-date terrain data sources potentially disastrous. Cultural features and terrain alterations may change dramatically between map surveying, printing, and subsequent updating. More often than not, topographic maps are out-dated or non-existent at the scales necessary for the planning and execution of military operations. The successful execution of operations and the survivability of men and equipment are dependent on the acquisition of accurate terrain data to update existing maps and aerial imagery.

The acquisition of current, up-to-date, aerial imagery poses a significant problem, particularly in potential areas of operation for units of the RDF. Aerial survey missions would be impractical or impossible based on time con-

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[13] Operations Army Field Manual 100-5.Washington,DC: US Government Printing Office,1982,pp.2-9.

tion, commanders make tactical decisions that ultimately affect the outcome of battles that support operational objectives and strategic goals within a theater of war.

1.3 GENERAL AND SPECIFIC PROBLEMS IN TERRAIN ANALYSIS

The technological advances made in the areas of mobility, firepower, and communications during the Twentieth century have dramatically affected the scale of tactical military operations. Prior to these advances, tactical commanders at the brigade and battalion level could personally observe the battlefield and control their units by visual or verbal means. Today, because of the tremendous advances in ground, sea, and air mobility; the lethality of weapons; and long range communications and information gathering systems, tactical commanders cannot personally "see and control" the battlefield. Friendly and enemy units are often far beyond the commander's "field of view" and are reduced to symbols on topographic maps. Observation and control are by electronic means, with all the advantages and disadvantages that they impose. Greater reliance is placed upon subordinate commanders executing orders which are the result of a detailed, thorough planning process based on the mission, enemy and friendly forces, time available, and terrain.

Army Field Manual 100-5, Operations, states,"One of the best investments of a commander's time before battle is an

ed on this thematic map. They include depressions, escarpments, ditches, fences, road cuts or rills, and man-made vehicular obstacles (craters, tank ditches). Excluded from this map are slope, vegetation, and surface material or drainage obstacles which appear on their respective thematic maps.

The acquisition of the basic terrain data elements for the compilation of the six thematic factors of the ITADB is based on the all-source analysis concept. All possible sources of terrain data pertaining to the area of operation are analyzed including: existing topographic maps; land use studies; environmental studies; soil surveys; soil, forestry, and other thematic maps; ground photographs; tourist guides and maps; and periodicals of related natural and social science. The most important source material and the basic tool for the production of the ITADB is aerial photography.[12] Through the application of manual image interpretation techniques, terrain data elements can be detected, identified, delineated, enumerated, and/or mensurated. These data, combined with available ancillary references, permit the analysis and classification of the environmental conditions of a specific area of operation. This information permits an evaluation of the military aspects of terrain and an estimate of friendly and enemy courses of action, completing the terrain analysis process. Based on this informa-

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[12] Ibid. pp. 1.

graphically portrayed using the choroplethic mapping model. (2) Vegetation - vegetation features which afford cover and concealment, present obstacles, or serve as landmarks are categorized by general type, canopy closure, height, and roughness factors (an estimate of vehicular movement degradation due to a particular type of vegetation). The spatial distribution of the vegetation categories is portrayed using the choroplethic mapping model. (3) Surface Materials - the surface material composition is classified using the Unified Soil Classification System (USCS) based on the grain size, plasticity, gradation, and organic content of soil material. Other categories include rock outcrops, permanent snowfields, evaporites, open water, and urban areas. The spatial distribution of these areal units which affect the trafficability in the area of operation is portrayed using the choroplethic mapping model. (4) Surface Drainage - surface drainage patterns, canals and irrigation systems, shorelines, offshore islands, and standing bodies of water are outlined on this thematic map. (5) Transportation - the existing road and rail network, bridges, and airfields are depicted on this thematic map. Roads and railroads are classified by type and number of lanes or tracks; bridges by type and capacity; and airfields by orientation, width, length, and surface materials. (6) Obstacles - all natural or man-made linear or areal features that restrict or divert cross-country movement of troops and/or vehicles are depict-

place variations are minimal. The categories are classified on the basis of selected attribute values or parameters. These parameters divide the category into subclasses at certain critical values or class intervals, which in turn identify the boundries between the non-overlapping regions. Mabbut described this landscape classification technique as the parametric approach to land evaluation.[10] This technique was initially developed for landscape reconnaissance surveys for military purposes but later used for land cover and land use surveys for resource management and planning at the local, state, and national policy levels.

Six tactically significant terrain factors, representing the natural and cultural features of the landscape, essential for evaluating the military aspects of terrain, have evolved into what is today termed the Tactical Terrain Analysis Data Base (TTADB).[11] The six factors of the TTADB include: (1) Slope - the natural or artificial degree or extent of deviation of the ground surface from the horizontal expressed as a percent of slope (the tangent of the slope angle X 100). The areal extent and distribution of slope categories which limit or restrict the mobility of dismounted troops and motorized, mechanized, or armored vehicles are

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[10] Mabbut, J.A. "Review of Concepts of Land Classification", Land Evaluation. South Melbourne: MacMillan and Co. Ltd. 1968, pp. 20

[11] DMA Product Specifications for the Hard Copy Tactical Terrain Analysis Data Base 1:50000. Washington, DC: DMA Hydrographic/Topographic Center, Jan 1982, pp. 1.

micro-relief features which restrict the mobility of forces within an area of operation; (4) Key Terrain - natural or man-made features which afford a marked advantage to the holder by denying access to an area, influencing movement along a route, or providing a vantage point for observation; and (5) Avenues of Approach - natural routes or transportation networks leading to key terrain features which are of sufficient width to permit the deployment of forces in tactical formations or permit unrestricted cross-country movement.

Although the focus of this study is at the tactical level or local scale, the military aspects of terrain remain constant regardless of the geographic scale. The scope or detail of the evaluation is the factor that varies with scale.

The initial step in military terrain analysis is essentially a data acquisition and classification process derived from the regional concept of geography.[8] Before the military aspects of terrain and the probable courses of action can be evaluated, the spatial distribution of the physical and cultural factors of the landscape which affect military operations must be analyzed and classified into single feature uniform regions.[9] These contiguous areas are classified using a single homogeneous category within which place-to-

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[8] Mitchell,C.W. Terrain Evaluation. London: Longman Group Ltd.1973,pp.23.

[9] Haggett,P. et al. Location Analysis in Human Geography. 2nd ed. NY: John Wiley and Sons,1977,Chap. 14,pp.451.

factors, all basic reconnaissance data essential for sound command decisions; (2) an evaluation of the effects of the environmental conditions upon tactical, administrative, and logistical factors and activities; and (3) an estimate of the effects of the characteristics of the area upon possible friendly and enemy courses of action.[6]

The second and third steps of the terrain analysis process are essential for the development of strategic plans and the application of tactical concepts. They are mission oriented, mission dependent, and require intelligence estimates of friendly and enemy troop strengths, unit compositions, locations, readiness, morale, and level of technology. The evaluation of the net effect of environmental conditions on tactical, administrative, and logistical factors and on probable courses of action also requires an evaluation of the military aspects of terrain.[7]

The military aspects of terrain include: (1) Cover and concealment- the protection from flat trajectory fire and aerial observation afforded by irregularities in the surface configuration of the landscape; (2) Observation and Fire - the ability to visually or electronically monitor and place flat trajectory weapons fire on an area from specific locations; (3) Obstacles - natural or man-made macro-relief and

---

[6] Peltier,L.C. and Pearcy G.E Military Geography. Princeton,NJ: D Van Nostrand Co.Inc.1966,pp.7.

[7] Military Geographic Intelligence (Terrain). Army Field Manual 30-10. Washington,DC: US Government Printing Office, 1978,pp.4-1.

logistical support before, during, and after engagements with the enemy. Although military doctrine establishes systematic procedures for the deployment of forces to take tactical advantage of the terrain, based upon the technological level of forces (firepower, communications, and mobility), the final selection of appropriate tactics is based on the evaluation of specific mission requirements, enemy capabilities, troops, equipment, and time available, and the effect of weather and terrain.

Weather and terrain affect military operations more significantly than any other physical factors. Cloud cover, precipitation, dust, light conditons, wind velocity and direction, and temperature extremes significantly affect the performance of men, equipment, weapon systems, and terrain conditions. Terrain, the physical and cultural features of the landscape, forms the natural structure of the battlefield and influences the mobility and visibility of forces. It provides opportunities and advantages, imposes limitations and disadvantages, giving a decisive edge to the commander who uses it best. Battles have been won or lost based upon the way commanders used the terrain to protect their own forces while destroying those of their opponents.

Peltier and Pearcy identified three steps in the terrain analysis process or three area analysis components: (1) a general description of the environmental conditions in the area of operation including weather, terrain, and cultural

STRATEGIC QUESTIONS:
(1) Where are the objectives to attack or defend?
(2) Where is the enemy located and where will he move?
(3) Where are obstacles and channels of movement?

TACTICAL QUESTIONS:
(1) Where to commit what force?
(2) Where to move and deploy?
(3) Where to attack or defend, advance or retreat?
(4) Where to place routes, bridges, landings, and defenses?

LOGISTICAL QUESTION
(1) Where can men, material, firepower, and supplies be deployed to support the tactical mission?

Answers to these questions are found through the analysis of the area of operation using the military terrain analysis process.

Military terrain analysis is defined as "the process of analyzing a geographic area to determine the effect of natural and man-made features of the landscape on military operations."[4] It is one of the initial steps in the planning process and an essential element for the successful execution of military operations.

Success in battle depends upon commanders selecting the appropriate tactics to win battles and engagements that support operational objectives and attain strategic goals within a theater of war.[5] Tactics involve the specific techniques military units use to deploy, position, and maneuver forces on the battlefield, provide fire support, and provide

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[4] Terrain Analysis. Army Field Manual 21-26. Washington,DC: US Government Printing Office,1978,pp.1-2.

[5] Operations. Army Field Manual 100-5. Washington,DC: US Government Printing Office,1982,pp.2-3.

on the conduct of operations at the brigade and/or battalion level.

The focus of this study is on the local or tactical level within this hierarchical nesting of geographic scale. Although the goals and objectives (missions) of brigades and battlions are prescribed by operational, regional, and global objectives, they must, in part, be based on the local or tactical capabilities of units to deploy, maneuver, support, and engage the enemy. These capabilities depend upon the physical and cultural conditions of the battlefield and the level of technology of the opposing forces. If the decision to pursue national objectives by military means is based on a keen sense of geopolitical realities, strategic accessibility, and strategic feasibility through tactical, technological, and logistical capabilities, the conduct of military operations becomes essentially a geographical problem of where to commit forces to battle.[3]

Military commanders at all levels make decisions about where to commit forces to battle based upon the evaluation of strategic, tactical, and logistical matters pertaining to their specific area of operation. The scope or detail of the evaluation naturally depends upon the geographic scale of the operation. Regardless of scale, answers to the following questions are essential to the decision making process and ultimately to the success of the operation:

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[3] Ibid. pp.7.

Strategic matters pertain to the identification of military objectives or targets and the evaluation of the capabilities of opposing forces to exert the force of arms in support of national objectives. Tactical matters pertain to the effects of the environment or battlefield conditions on military organization, training, and decisions. Logistical matters pertain to technology, planning, and the deployment of men, material, and supplies essential for tactical success within a specific theater of operation.

Strategic, tactical, and logistical matters are evaluated at various scales.[2] At the global scale, these matters are evaluated in terms of the National Grand Strategy (those national geopolitical goals or objectives determined by national desires, characteristics, and resources) and the pursuit of national objectives by military means. At the regional scale, they are evaluated in terms of a specific theater of war or geographic region in which an army would operate (i.e. US Army Europe) in support of objectives and goals of the National Grand Strategy. At the operational scale, strategic, tactical, and logistical matters are evaluated in terms of the net effect of a specific geographic location on the maneuver and support of major field commands (corps and division). Finally, at the local scale, these matters are evaluated in terms of specific physical and cultural conditions of potential battlefields and their effect

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[2] O'Sullivan, P. and Miller, J.W.Jr. The Geography of Warfare NY: Martin's Press, 1983, pp.5.

TABLE 2

USGS Land Cover and Land Use Classification System

LEVEL I		LEVEL II	
1	URBAN or BUILT-UP LAND	11	Residential
		12	Commercial and Services
		13	Industrial
		14	Transportation,Communications,Utilities
		15	Industrial and Commercial Complex
		16	Mixed Urban Land
		17	Other Urban Land
2	AGRICULTURAL LAND	21	Cropland and Pasture
		22	Orchards,Groves,Vineyards, Nurseries,Ornamental Horticultural Areas
		23	Confined Feeding Operations
		24	Other Agricultural Land
3	RANGELAND	31	Herbaceous Rangeland
		32	Shrub and Brush Rangeland
		33	Mixed Rangeland
4	FOREST LAND	41	Deciduous Forest Land
		42	Evergreen Forest Land
		43	Mixed Forest Land
5	WATER	51	Streams and Canals
		52	Lakes
		53	Reservoirs
		54	Bays and Estuaries
6	WETLAND	61	Forested Wetland
		62	Nonforested Wetland
7	BARREN LAND	71	Dry Salt Flats
		72	Beaches
		73	Other Sandy Areas
		74	Bare Exposed Rock
		75	Strip Mines,Quarries, Pits
		76	Transitional Areas
		77	Mixed Barren Land
8	TUNDRA	81	Shrub and Brush Tundra
		82	Herbaceous Tundra
		83	Bare Ground Tundra
		84	Wet Tundra
		85	Mixed Tundra

9	PERENNIAL SNOW or ICE	91	Perennial Snowfields
		92	Glaciers

This resource-oriented, hierarchical classification system provides a standardized convention that defines land cover types at the generalized I and II levels, yet permits the flexibility for user specific definitions at the III and IV levels or below. With minor modifications at the I and II levels, and with specific military tactical terrain factors defining level III classes, the USGS system could be used as a standard convention for the Vegetation, Surface Drainage, Surface Material, and Transportation factors of the TIADB.

The application of LANDSAT TM data as a potential source of tactical terrain data is currently under study at the Defense Mapping Agency (DMA). DMA is responsible for providing the Department of Defense with terrain information in both cartographic and digital formats. This includes compilation of the TIADB, 1:50,000 (local or tactical scale); the Planning Terrain Analysis Data Base (PTADB), 1:250,000 (regional and/or operational scale); and a series of visibility and mobility maps pertaining to the military aspects of terrain (at both scales).

DMA's approach to providing this information is, by necessity, highly centralized. Data acquisition, analysis, classification, appraisal, and product completion are accomplished at a centralized location by multidisciplinary terrain

analysis teams using a synergistic approach.[20] Consequently, the digital image processing of LANDSAT data is being considered in the same light. The computer processing of full LANDSAT scenes (approximately 32,000 square kilometers) requires mainframe or minicomputer hardware and software systems to handle the huge amounts of data involved. This equipment is only available in centralized locations such as DMA. However, a potential problem arises in the timely dissemination of terrain information from this centralized location to tactical unit commanders and staffs.

Brigade and battalion size tactical units of the RDF must be prepared to deploy anywhere in the world within 18 hours of notification. This 18 hour period encompasses the total time required to assemble units; issue arms, ammunition, and supplies; plan and issue orders to subordinate units; rehearse critical aspects of the mission; move to departure airfields or port facilities; and deploy to the area of operation. If terrain information products are not available to intelligence and operations staffs and unit commanders within the first few critical hours of the planning process, terrain information must be appraised using terrain data acquired from existing topographic maps, aerial imagery, or anything else that may provide an insight to the conditions of the battlefield. In the case of the Grenada operation in

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[20] Howard, J."Application of Thematic Mapping Techniques in Terrain Analysis".ACSM/ASP Conference Paper, Falls Church:ASP, Jan 1980, pp.3.

class of interest.

Apple II series microcomputer hardware currently exists at the proposed decentralized unit levels. MICROIX, a turn-key software and hardware system consisting of "militarized" Apple II hardware, was fielded in 1985. The MICROIX system is compatible with the APPLEPIPS software system with minor modifications to the card slot configuration and the PIPS hard copy algorithm.

Providing the LANDSAT TM data can be obtained in the appropriate format and trained digital image analysts are available at the decentralized levels, two specific questions remain. The first concerns data acquisition and classification. Which IIADB factors can be obtained from the analysis and classification of the digital TM data? The second concerns the accuracy of the resulting land cover maps. What is the accuracy of the spatial distribution of the land cover classes depicted and how does it compare to the actual land covers present on the ground?

1.4 PURPOSE AND OBJECTIVES

The purpose of this study is to determine if accurate tactical terrain data can be obtained through the digital image processing of LANDSAT Thematic Mapper data using the Personal Image Processing System designed for use with the Apple II series microcomputer.

1983, primary terrain data sources included recent aerial imagery, tourist guide maps, and petroleum company road maps.

A potential solution to the problem of timely dissemination of terrain data or information is the decentralization of the digital image processing of LANDSAT data to the user level. This would provide current land cover information (derived from recently acquired LANDSAT TM data) to update existing topographic maps and aerial imagery. Development of microcomputer digital image processing systems, in the last several years, indicates that the decentralization of this process is, in fact, entirely feasible.

The Personal Image Processing System (PIPS), designed for use with the Apple II series microcomputer by the TELESYS Group, is one example of this type of system. It is described as

> a very effective low-cost aid for image processing. Documentation is excellent and the programs are easy to use for students with a limited knowledge of computers or image processing techniques.[21]

APPLEPIPS permits the interactive color monitor display of black and white hard copy display of single band digital data; image enhancement techniques to improve the visual interpretation of the data; and multi-band thematic classification of land cover categories. Land cover classification is based on a user-specified spectral signature for each

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[21] Welch, R., et al. "Microcomputers in the Mapping Sciences", Computer Graphics World, Vol.6, No.2, Feb 1983, pp.2.

The major objectives of this research are as follows: (1) to identify the Tactical Terrain Analysis Data Base factors that may be obtained through the digital image processing of LANDSAT TM data by reviewing related literature pertaining to land cover application projects using LANDSAT data and the supervised approach to digital image processing; (2) to complete a land cover map for each of three North Carolina study areas, representing typical vegetated land cover categories found in the Piedmont physiographic region, using: a) a modified USGS land cover classification system as a proposed standard convention for the TTADB Vegetation, Surface Materials, Surface Drainage, and Transportation factors; b) LANDSAT TM data in a 5 1/4 inch floppy disk format; and c) the Apple II Personal Image Processing System; and (3) to evaluate the accuracy of the land cover maps using a site specific accuracy assessment technique for supervised digital image processing to determine if APPLEPIPS land cover maps meet the USGS' 85 percent minimum accuracy standard. The potential for using microcomputer digital image processing techniques to obtain tactical terrain data from LANDSAT multispectral digital imagery will be demonstrated, if there is no significant difference between the regions of uniform land cover identified on the APPLEPIPS land cover maps and the regions identified in the study areas by ground observation.

Chapter II

RELATED LITERATURE

2.1 THE LANDSCAPE AND QUANTITATIVE APPROACHES TO TERRAIN EVALUATION

Mitchell identified two basic approaches for the acquisition, analysis, and classification of terrain data for practical terrain evaluation purposes.[22] The first, the physiographic or landscape approach, attempts to classify terrain into natural units (uniform regions) representing finite physical regions identifiable on the ground and from the air, at two distinct scales.

Small scale units (large uniform regions) are identified based on the Davisian causual factors of structure, process, stage, and climate. These regions are termed genetic, morphogenetic, or recurring land systems and are identified at scales ranging from 1:250,000 to 1:1,000,000 or smaller. The large natural regions resulting from this genetic classification are internally complex and often overly generalized in order to accomodate both the natural and cultural features of the landscape. Vague boundaries and an unsuitable scale for detailed land cover or land use applications are also disadvantages of this small scale approach.

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[22] Mitchell, C.W. Terrain Evaluation, London: Longman Group Ltd. 1973. pp. 26.

Large scale units (small uniform regions) are identified through the analysis of characteristic terrain patterns of homogeneous, non-recurring physiographic or landscape units termed facets, at scales ranging from 1:100,000 to 1:50,000 or larger.

Mabbut described the advantages of the landscape approach to terrain classification as:[23] (1) establishing a rational hierarchy of natural regions; (2) facilitating the explanation of the concept of regionalization; (3) assisting in the initial reconnaissance survey of an area; and (4) permitting the prediction of landscape characteristics based on a comparison of image pattern elements with image interpretation keys. This classification approach is based on the visual recognition of characteristic components of the landscape (topography, drainage patterns, vegetation, surface materials) and is particularly applicable to the manual interpretation of remote sensor imagery. Large and/or small scale uniform regions are identified based on a qualitative or subjective visual interpretation of tone, texture, pattern, size, shape, and association.

The second approach to terrain classification, the parametric or quantitative approach, attempts to classify uniform regions based on selected landscape attribute values or parameters of particular interest for specific applications,

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[23] Mabbut,J.A."Review of Concepts of Land Classification", Land Evaluation. South Melbourne: McMillan and Co.Ltd.1968,pp.11.

at either the land system or facet scale. Inherent problems of this approach include difficulties in: (1) identifying relevant parameters or attribute values to be mapped based on the specific purpose of the land cover project; (2) identifying limiting values which separate classes and subclasses of interest; (3) collecting more data or greater detail increases the "cost" of the classification project; (4) recognizing the resulting land cover classes on the ground; and (5) the sampling methodology used limits the predictability of the approach. The parametric approach does, however, avoid the subjectivity of the landscape approach by defining uniform regions quantitatively, permitting comparisons and affording consistency. It is particularly applicable to the computer analysis of digital terrain data acquired by automatic remote sensing scanners.[24]

Despite the differences between the two approaches, they should be considered as ultimately complementary rather than conflicting.[25] The relative advantages and disadvantages of each approach vary with (1) the specific purpose of a particular application project; (2) time, funding, and geographic scale; and (3) the type of data (ground survey data, archival data, remote sensor data).

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[24] ibid. pp.21.

[25] Mitchell, C.W. Terrain Evaluation. London: Longman Group Ltd. 1973, pp.36.

The parametric approach to terrain classification has been most fully developed for military purposes by the United States Army Engineer Waterways Experiment Station (USAEWES) at Vicksburg, Mississippi.[26] The initial research program, begun in 1953, focused on the identification of key terrain factors affecting military activities. These factors were limited to a manageable number which were easily visualized, militarily significant, transferable, and gave a complete picture of the terrain.

The numerical values of the parameters identifying subdivisions within the terrain classes had to be suitable as mapping units and related to factors limiting the mobility and visibility of men and equipment. Based on these guidelines, terrain factors were identified and grouped into "factor families".

There were two primary factor families in the Vicksburg approach to the parametric classification of terrain. The first, the aggregate and general factor family included: (1) physiography - the generalization of the surface geometry into plateau, plain, hill, and mountain classes; (2) hypsometry - representing altitude classes (<5000 ft; 5000-9000 ft; >9000 ft) affecting vehicle operational efficiency; and (3) landform and surface conditions - depicted on physiographic sketch maps and geomorphic outline maps. Other surface geometry factors included characteristic

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[26] Ibid. pp. 1.

slope, relief, occurrence of slopes >50 percent, and characteristic plan profile.

The second group, the ground and vegetation factor family, consisted of: (1) soil type - soil texture and proportion of bare rock exposed at the surface; (2) soil consistency - degree of layering, cohesiveness, and crustiness; (3) surface rock - lithology of the exposed surface rock; (4) vegetation - a quantified physiognomic classification based on the physical form and outward superficial appearance of plants; and (5) microrelief - vertical obstacles of less than 10 feet.

Applications of the Vicksburg approach for terrain classification to different geographic regions of the world demonstrated the utility of the approach for providing information concerning trafficability, mobility, and visibility.[27] Interpretation of remote sensor imagery, primarily aerial photography, permitted the recognition of several physiographic and soil/vegetation factors by trained image analysts.

The factor families of the Vicksburg approach have been modified into the six terrain factors of the Defense Mapping Agency's Tactical Terrain Analysis Data Base, which includes slope, vegetation, surface materials, surface drainage, transportation, and obstacles.

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[27] Ibid. pp.85.

The slope parameter values are based on the maximum percent of slope which will permit, degrade, or prevent foot soldiers, wheeled vehicles, and tracked vehicles (tanks and armored personnel carriers) from traversing terrain during the course of military operations. These attribute values or slope categories include (but are not limited to) the following classes: 0-3, 3-10, 10-20, 20-30, 30-40, 40-45, >45 percent. The primary slope data sources are topographic maps, stereo aerial photography, and ground measurements. Although stereo LANDSAT images have been prepared using computer digital image processing techniques,[28] they are not widely available and will not be used in this research project. Therefore, the acquisition of slope data from LANDSAT TM imagery will not be evaluated in this study.

Linear and areal obstacle parameter values are based on maximum vertical and horizontal microrelief features which degrade or prevent vehicular mobility. These values are typically less than 10-20 feet and are not detectable with the LANDSAT TM resolution of 30x30 meters. Therefore, the acquisition of obstacle data from LANDSAT TM imagery will not be evaluated in this study.

The four terrain factors of the ITADB that will be evaluated include: (1) Vegetation - the physiognomic classification of vegetation based on the physical form or outward su-

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[28] Welch,R."3D Terrain Models from LANDSAT 4 Digital Image Data", Technical Papers 50th Annual Meeting American Society of Photogrammetry, Falls Church: ASP,Mar 1984.

[illegible] appearance of plants including form; leaf [illegible] shape, size, and texture; and ground coverage.[29] [illegible] the vegetation categories of the ITnDB.[30] The [illegible] factor (VHF), a subjective estimate of [illegible] movement degradation due to a particular type of [illegible] stem diameter and spacing, will not be evaluated in this study.

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[29] Kuchler, A.W. "A Physiognomic Classification of Vegetation" Annals of the Association of American Geographers. Washington, DC: AAG, 1949, Vol. 39, pp. 201-210.

[30] DMA Product Specifications for the Hard Copy Tactical Terrain Analysis Data Base 1:50000. Washington, DC: DMA Hydrographic/Topographic Center, Jan. 1982, pp. 5-9.

TABLE 3

USGS Vegetation Classification System

TYPE	
AGRICULTURAL	Dry crops Wet crops Terraced crops Shifting cultivation
BRUSHLAND/SCRUB	
FORESTED	Coniferous forest Deciduous forest Mixed forest Orchards
GRASSLANDS	Grass/Pasture/Meadows Grass with trees
FOREST CLEARING SWAMP MARSH/BOG WETLANDS VINEYARDS/HOPS NURSERY/CANE BARE GROUND OPEN WATER BUILT-UP AREAS (URBAN)	

PERCENT TREE CANOPY CLOSURE
0-25
25-50
50-75
75-100

FOREST UNDERGROWTH
DENSE
SPARSE

HEIGHT
(meters)

0-5	10-15	25-30
5-9	15-20	30-35
9-10	20-25	>35

(2) Surface Materials - table 4 lists the surface ma-

One of the objectives of the study was to determine the vegetation cover types that could be delineated from LANDSAT TM bands 1 - 5. The land cover classification system used for the study was a modified USGS classification system with 8 Level I classes, 21 Level II classes, and 33 Level III classes.[43] Table 9 lists the classification system used for the Saginaw River Basin Study.

Unsupervised cluster analysis and maximum likelihood classification algorithms of the ELAS system resulted in 23 land cover/vegetation classes identifiable on the August 17, 1982 TM image used in the study.

Although the research project has not been completed (accuracy and reliability evaluation remaining) the preliminary results indicate a high potential for the use of TM data to map land cover for wildlife habitat evaluation.

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tion in the Saginaw River Basin." Technical Papers 51st Annual Meeting American Society of Photogrammetry. Falls Church: ASP, March 1981, Vol. 1. Pp. 85-97.

[43] Ibid. pp. [illegible].

TABLE 9

Predicted Percent Canopy Closure Accuracy

Canopy Closure Classes	TM 5	TM 3-5,7
0 - 25	67.6	71.2
25 - 50	29.2	29.2
50 - 75	37.5	35.1
75 - 100	48.7	57.2

Canopy Closure Classes	TM 5	TM 3-5,7
0 - 25	67.6	71.2
25 - 75	73.9	60.7
75 - 100	48.7	57.2

Additional findings included: (1) The identification of a negative correlation between spectral reflectance and percent canopy closure in all 7 bands of the TMs data, that is, as percent canopy closure increases, mean spectral response decreased; (2) The spectral reflectance of low moisture soils and vegetation was greater than that of turgid vegetation; (3) TMs band 5 possessed the highest correlation coefficient; (4) TM bands 1, 5 and 7 (not available in MSS data) were best suited for assessing percent canopy closure from spectral response; and (5) The accuracy of predictions from the regression model increased when the spectral contrast between the forest vegetation and its background were greatest (turgid vegetation against a bare soil/senesced grass background).

Lunetta and Congalton evaluated the application of simulated TM data for use in wildlife habitat evaluation.[42]

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[42] Lunetta, R.S. and Congalton, R.G. et al. "Using Remotely Sensed Data to Map Vegetative Cover for Habitat Evalua-

project was to analyze the correlation between the percent forest canopy closure and simulated Thematic Mapper data acquired in September 1981 from a scanner mounted on a conventional aerial platform. Regression models were developed from the correlation results to create predictive maps of percent canopy closure. The closure categories chosen for the project correspond to those of the Vegetation classification system of the FIADB. Table 7 lists the correlation coefficients and coefficients of determination for each TMs band.

TABLE 7

TMs Correlation Coefficients and Coefficients of Determination

TMs Band	r	r Squared
1	-.757	.584
2	-.663	.464
3	-.666	.437
4	-.088	.020
5	-.797	.651
6	-.597	.329
7	-.763	.582

Table 8 lists the accuracy of the percent canopy closure predicted by the regression models for the four canopy closure classes of the FIADB using TMs band 5 only and TMs bands 3, 4, 5, and 7 at the 99.99 percent confidence level. Also listed are the results for 5 closure classes with collapsed percentage intervals.

ble and near infrared wavelengths. Upland agriculture, water, and urban/bare soil classes, however, were easily separated and classified. This project recommended the acquisition of LANDSAT TM data in the spring or fall months in southeastern US environments if the data are to be used for wetland mapping.

Richardson completed a wetland classification of Cape Cod, Massachusetts using LANDSAT TM data acquired on December 8, 1982.[40] Thirty one spectral signatures were identified using an unsupervised clustering algorithm and maximum likelihood classification. Land cover categories mapped included water (clear, turbid, tidal flat, shoreline); wetlands (saltwater, brackish water, fresh water); developed upland (urban, suburban, beach); and natural upland (softwoods, hardwoods, mixed, open, agricultural, bare soil). Specific features identified in the scene included docks, parking lots, piers, power plant cooling towers, and grassy medians separating highways.

Butera analyzed the potential for obtaining forest canopy closure percentages from LANDSAT TM simulated data in the San Juan National Forest, Colorado.[41] The objective of the

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[40] Richardson, K.A. "Wetlands Classification using LANDSAT TM Data Unsupervised Classification Approach", ibid. pp.154-156.

[41] Butera, M.C. "A Correlation Analysis of Percent Canopy Closure versus TMs Spectral Response for Selected Forest Sites in San Juan National Forest, Colorado", NASA Technical Report 212.
Earth Resources Lab: NASA, Nov 83.

terns and increasing the contrast between highly reflective areas (man-made structures/features) and areas of lower reflectance (vegetated and residential areas).

The following land cover projects are representative of academic, governmental, and private sector research involving the application of LANDSAT MSS and TM data and are directly applicable to the ITADB factors of vegetation, surface materials, drainage, transportation, and urban areas.

2.2.1 Vegetation

Jensen evaluated the potential of LANDSAT TM data for providing information concerning the distribution and conditions of South Carolina inland wetlands in the Savannah River watershed.[39] The five wetland classes evaluated included persistent emergent marsh, nonpersistent emergent marsh, mixed deciduous bottomland forest, scrub/shrub, and mixed deciduous swamp forest. Other classes evaluated included upland agriculture, water, and urban/bare soil.

The TM image used for the analysis was acquired on August 26, 1982, late in the growing season. As a result, only TM bands 4 and 5 provided significant information to separate the wetland classes due to similarities in spectral reflectance levels of the various vegetation classes in the visi-

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[39] Jensen, J.R. "Multispectral Remote Sensing of Inland Wetlands in South Carolina: Selecting the Appropriate Sensor", Proceedings, 10th International Symposium on Machine Processing of Remotely Sensed Data. West Lafayette: Purdue Research Foundation, 1984, pp.144-152.

(water, soybeans, rice, fallow/barren, hardwood forest).

The Reelfoot Lake study area contained five forest and wetland land cover classes (cypress, mixed hardwood, willow/cypress, brush, floating acquatics) which were classified using TM bands 2,3,4,5, and 7 at an overall accuracy of 95.36 percent.

The Union City, TN study area consisted of six Level I and II urban, forest, and agricultural classes (road and inert materials, commercial/industrial development, transitional/grassland areas, forest land, and agricultural/bare soil). Due to difficulties in delineating ground truth polygons for the transitional/grassland and road/inert classes, these categories were combined with the other four classes. The overall classification accuracy of the final four class land cover map was 89.9 percent.

Principal component analysis (PCA) was also evaluated as an image enhancement technique for TM data. PCA is a statistical technique which decomposes the total variation of a multivariate data set into linearly independent components of decreasing magnitude (1st, 2d ... nth principal component based on, in this case, the number of LANDSAT spectral bands used in the analysis).[38] Results indicated that PCA enhancement improved the visual interpretation of the digital imagery, permitting identification of structures and road pat-

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[38] Pirkle, F.L. "Principal Component Analysis as a Tool for Interpretting NURE Aerial Radiometric Survey Data", Journal of Geology. 1980, V88, pp.57-67.

The launch of LANDSAT 4, on July 16, 1982 with its Thematic Mapper scanning radiometer, permitted the acquisition of multispectral digital imagery at a far greater spatial, spectral, temporal, and radiometric resolution than any of its predecessors. LANDSAT 5, launched on March 1, 1984, completed the second generation of earth orbiting observation satellites and propelled the LANDSAT system from the experimental to the operational phase.

The preliminary evaluation of LANDSAT 4 TM data, in November 1982, indicated a significant improvement in the classification accuracy of the land cover categories evaluated using computer-assisted processing techniques.[37] The evaluation study consisted of an analysis of LANDSAT 4 TM data using digital enhancement and classification techniques for

three study areas (Poinsett County, Arkansas; Reelfoot Lake, Tennessee; and Union City, Tennessee) representing typical agricultural, forest, wetland, and urban land cover classes in the southern United States.

A comparison between TM data and MSS data for the Arkansas study area resulted in a significantly better overall classification accuracy (TM bands 2,4,5 - 97.00%; MSS bands 2,4 - 80.91%) for five land cover classes in the study area

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[37] Quattochi, D.A. et al. "An Initial Analysis of LANDSAT 4 TM Data for the Classification of Agricultural, Forested, Wetland, and Urban Land Covers", NASA Report No. 215, NSTL Station, Ms: NASA, NOV 1982.

Numerous multi-disciplinary application projects, during the past decade, clearly demonstrated the potential of LANDSAT 1-3 MSS data to provide up-to-data land cover information for resource managers and planners. One example of the application of computer-assisted LANDSAT MSS digital image processing is the New Jersey land cover mapping project.[36]

The NJ Division of State and Regional Planning initiated a project to map and inventory the land cover of the state using LANDSAT MSS digital data acquired in 1976. The purpose of the project was to provide inexpensive, accurate, up-to-date land cover information for the preparation of a state water quality management plan. The resulting 1:24,000 scale land cover maps depicted eight Level I land cover classes which included forest, pasture/vacant, cropland, high density urban, low density urban, barren/extractive, wetlands, and surface water.

The Bureau's project evaluation study indicated that the computer assisted digital processing techniques used for preparing the land cover maps were approximately one third the cost of alternative mapping techniques (conventional aerial imagery acquisition, interpretation, and map production) and attained a 95 percent accuracy, even with the 1.4 acre resolution of the MSS scanner.

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[36] Gosted, J. and Mills, T. Maps from orbit Trenton: Bureau of Regional Planning, Jan 1978.

particular land cover type. Because of the spatial resolution of the TM scanner (30x30 meters), the integer value for each pixel represents the average spectral reflectance and/or emittance from vegetation, soil and rock materials, shadows, and man-made features, present within the IFOV of the scanner. The set of DN values representing a specific cover type or surface feature is a quantitative, but relative set of measurements corresponding to a particular set of MSS data.

The term 'land cover' is defined as

> the vegetational and artificial construction covering the land surface.[34]

Another term, which is interrelated and often interchanged with land cover, is 'land use'. Land use is defined as

> man's activities on land which are directly related to the land.[35]

The majority of LANDSAT data application projects yield information pertaining to land cover rather than land use. Remote sensors record characteristics of the land's natural and artificial cover rather than activity or use. Land use, in turn, is interpretted from patterns, tones, textures, shapes, associations, and spectral signatures commonly associated with a particular land cover type.

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[34] Burley,T.M."Land Use or Land Utilization?", The Professional Geographer. Washington,DC: AAG,V13,No.6,pp.18-20.

[35] Clawson,M. and Stewart,C.L. Land Use Information. Baltimore: The John Hopkins Press for the Future Inc.1965.

TABLE 6

ITALY Transportation Classification System

ROADS	All weather hard surface dual/divided highway All weather hard surface highway All weather loose surface road Fair weather loose surface road Cart track Under construction Width Gradient (slope) Radius of curvature
ROAD BRIDGES	Overhead clearance Load class Width Length Bypass
RAIL BRIDGES	Width Length Overhead clearance
RAILROADS	Guage Number of tracks, passing tracks, siding tracks Electrified Dismantled Rail yards
AIRFIELDS	Length Width Surface - paved/unpaved Orientation

2.2 LAND COVER APPLICATION PROJECTS

The parameter used to classify uniform land cover regions, in the computer assisted analysis of LANDSAT digital imagery, is the characteristic spectral response pattern or spectral signature. A spectral signature represents a set of measurements (digital numbers) recorded by the LANDSAT's multispectral scanners (MSS and TM) that are unique to a

Other surface drainage features include on and/or off route fording sites and dams. Dams are classified by size (<5 meters; >=5 meters) and construction material type (concrete, earth and stone, earthen, and other).

(5) Transportation - Table 6 lists the road and rail network, bridge, and airfield classification system.[33] Other transportation features of interest include tunnels (height and width clearance) and ferry sites.

As stated previously, the primary source of terrain data for the TTAB is aerial photography. Using manual interpretation techniques the above detailed data elements of the Vegetation, Surface Material, Surface Drainage, and Transportation terrain factors can be enumerated and mensurated or identified and delineated through the recognition of characteristic pattern elements using the landscape approach to terrain classification. If military terrain analysts are found to apply the parametric approach to terrain classification, using computer assisted analysis of LANDSAT IM digital imagery (in the absence of up-to-date aerial photographs), then the detailed terrain data elements of the TTAB obtainable through digital image processing techniques must be identified.

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[33] ibid. pp. 17-23.

TABLE 5

TIABLE Surface Drainage Classification System

TYPE

OPEN WATER	Lakes/Ponds/Reservoirs (100x50meters)
Stream	Intermittant Ephemeral Perennial Tidal
CANAL/CHANNELIZED STREAM/DITCH	Canal Channelized Stream Irrigation Canal Drainage Canal

GAP WIDTH
(meters)
<=4.5
>4.5 <=18
>18

BOTTOM MATERIALS
(USCS Classification System)

BANK VEGETATION
Dense
Sparse

BANK PERCENT SLOPE
<=30
>30 <=45
>45 <=60
>60

AVERAGE WATER VELOCITY
(meter/second)
<=2.5
> 2.5
no data

AVERAGE WATER DEPTH
(meters)
<0.8
>0.8 <=1.6
>1.6 <=2.4
>2.4
no data

drainage maps, include shorelines; offshore islands (>250 meters in both dimensions or >1000 meters in the longest dimension); large rivers (gap widths >142 meters and >1000 meters in length); and lakes (>250 meters in both dimensions or >1000 meters in the longest dimension).[32] Table 5 lists the detailed surface drainage features, some of which require ground data acquisition techniques for compilation.

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[32] Ibid. pp. 15-16.

terial categories depicted on this factor map.[31] The Corps of Engineers' Unified Soil Classification System (USCS) is used to classify soil materials based on the grain size (C - clay,<.002mm; M - silt,.002-.05mm; S - sand,.05-2.0mm; and G - gravel,> 2.0mm), plasticity (L - percent moisture content by weight <50%; H - percent moisture content by weight >=50%), gradation (P - poorly graded; W - well graded), and organic content (O - high organic content; Pt - peat). Other surface materials include rock outcrops (RK), evaporites (EV), permanent snowfields (PS), open water (W), and not evaluated and/or urban areas (X).

TABLE 4

ITABD Surface Material Categories

USCS SOIL TYPES

COARSE SOILS		FINE SOILS	
GW	SW	ML	CL
GP	SP	OL	OH
GM	SM	MH	PT
GC	SC	CH	

OTHER CATEGORIES

RK	EV	W
PS	X	

Surface Drainage - Surface drainage features are depicted at two levels of detail. General drainage features, appearing on the Vegetation, Slope, Surface Material and Surface

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[31] Ibid. pp.IV-5.

Table 6

Saginaw River Basin Land Cover Classification System

Level I	Level II	Level III	
Wetlands	Forested	Oak	Walnut
		Hickory	Poplar
		Maple	Aspen
		Ash	Willow
		Elm	
	Scrub/shrub (<20 ft)	Poplar	
		Button Bush	
		Willow	
	Nonforested	Cattails	Grasses
		Sedges	Docks
		Rushes	Smart Weed
		Phragmites	
		Mixed grasses	
		Purple Loose-Strife	
	Floating	Arrow arum	
		Lemna	
Agricultural land	Fallow		
	Orchard		
	Crops	Corn	Barley
		Wheat	Alfalfa
		Beans	Clover
		Oats	Buckwheat
		Sugar beets	
Forest land	Coniferous		
	Mixed		
	Deciduous	Walnut	Oak
		Poplar	Hickory
		Aspen	Maple
		Willow	Ash
		Elm	
Open water	Deep open water (> 15 ft)		
	Shallow water		
	Shallow/marsh		
Urban land	Deciduous		
	Scrub/shrub	Poplar	
		Ash	
		Willow	
	Mixed land		

Barren land	Extracting Mud Flats Pavement Sand
Urban	Lawn
Unknown	Unclassified

2.2.2 Surface Materials

Ni evaluated the application of digital image enhancement processing of Landsat MSS data for terrain evaluation in Beijing, China.[44] A subset from a September 10,1978 LANDSAT MSS image, encompassing 250 square kilometers of southern Shunyi County of Beijing, China, was digitally enhanced and visually interpreted to map land systems and land facets at a scale of 1:100,000. Table 10 lists the geomorphological classification system used in this mapping project.[45]

Dwivedi evaluated the application of digital enhancement techniques to LANDSAT MSS data for reconnaissance soil mapping, using a monoscopic interpretation approach in the Anantapur district, Andhra Pradesh, India.[46] This study demonstrated the utility of applying image enhancement tech-

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[44] Ni, S.X. "Application of Digital Image Enhancement Processing of LANDSAT Data for Terrain Mapping of Beijing (Peking), China," Proceedings 1984 Machine Processing of Remotely Sensed Data Symposium, West Lafayette: Purdue Research Foundation, 1984, pp. 108-116.

[45] Ibid. p. 114.

[46] Dwivedi,R.S. "Utility of Some Image Enhancement Techniques for Reconnaissance Soil Mapping - A Case Study from Southern India", Ibid. pp. 266-274.

TABLE 10

Geomorphological Classification System Beijing, China

I	II
Diluvial Platform	High Platform Lowland between Platform
River Valley Basin	River Terrace and Alluvial Flat Eroded Platform adjacent to River Valley Basin
Volcanic Foothill	High Valley Basin
Granite Mountain	River Valley and Gully Granite Hill adjacent to River Valley Granite Mountain
Carbonate Mountain	River Valley and Gully Carbonate hill adjacent to River Valley Carbonate Mountain

[illegible] to MSS data (density slicing, ratioing, linear and non-linear contrast stretching) for reconnaissance soil [illegible] in a hard rock terrain. Soils containing sand and [illegible] particles were differentiated using these computer-assisted image enhancement techniques.

[illegible] evaluated the application of image enhancement techniques (band ratioing and density slicing) for the preparation of geologic maps from LANDSAT 4 TM and TMS data.[47] [illegible] of TM bands 5:4 and 5:7 for an arid study area in [illegible] Valley, California improved the visual interpretation

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[47] [illegible], D.G. et.al. "Contribution of LANDSAT 4 TM Data to Geologic Exploration," Chevy Chase, MD: Earth Satellite Corp. NASA, 1984.

of the image. In particular, the 5:2 ratio permitted the identification of areas with high ferric iron content and vegetation. The 5:7 ratio improved the identification of hydroxal bearing minerals and other surface materials containing free water (clays, hydrated salts, and vegetation).

Hoffer identified five factors affecting the absorptance and reflectance characteristics of soil, which, together with the improved spatial and spectral resolution of TM data, may permit the mapping of surface materials at the level of detail needed for the TIADB.[48] These factors include: (1) Moisture Content - as soil moisture content increases, spectral reflectance decreases; (2) Soil Particle Size - as the soil particle size decreases, spectral reflectance increases; (3) Organic Content - as the percentage of organic materials increases, spectral reflectance decreases; (4) Surface Roughness - as the roughness of the soil surface increases, spectral reflectance decreases; and (5) Iron Oxide Content - as the amount of iron oxide increases, spectral reflectance decreases. Additionally, the spectral reflectance characteristic of dry soils is, generally, one of increasing level of reflectance with increasing wavelength, particularly in the visible and near infrared portion of the electromagnetic spectrum.

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[48] Hoffer, R.M. "Bio-physical Considerations in Applying Computer-Aided Analysis Techniques to Remote Sensor Data," Swain, P.H. and Swain, R.M. Remote Sensing the Quantitative Approach. NY: McGraw-Hill Inc, 1978, Chapter 5, pp. 227-289.

2.2.3 Surface Drainage

Lauer reported that the improved spatial resolution of TM data aided in the location of roads, small ponds, and other smaller surface features not previously identifiable on MSS data.[49] TM bands 5 and 7 were also identified as a new information source for the identification of water resources, wetland vegetation and other terrain features.

Range evaluated the application of LANDSAT MSS data for obtaining surface drainage network information on a number of watersheds in the US.[50] Their comparison of LANDSAT derived data with that from topographic maps indicated that watershed area, shape, and channel sinuosity estimates from Landsat 1:100,000 scale images were comparable to data obtained from 1:62,500 scale topographic maps, for well dissected, moderately vegetated terrain. Flat or heavily forested terrain results were comparable to 1:250,000 scale maps.

Other water resource application of LANDSAT TM and MSS data include:[51] (1) determination of water boundaries and surface water area and volume; (2) mapping of floods and

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[49] Lauer, D.T. Quarterly Report: LANDSAT 4 Investigation of TM & MSS Applications. Sioux Falls: Eros Data Center 24 Oct 83.

[50] Salmonson, V.V. et.al. "Water Resources Assessment," Manual of Remote Sensing Second Ed., Falls Church: ASP, Vol.II, Chapter 29, pp. 1548.

[51] Freden, S.C. "Survey of Landsat Program," Short, N.M. Mission to Earth: Landsat Views the World. Washington, DC NASA. 1976.

flood plains; (3) areal extent of snow and snow boundaries; (4) identification and mensuration of glacial features; (5) identification of sediment and turbidity patterns; (6) determination of water depth; (7) delineation of irrigated fields; and (8) inventory of lakes.

2.2.4 Transportation and Urban Areas

Wang evaluated the application of a multichannel hierarchical clustering algorithm to LANDSAT TM data for deriving detailed land use/land cover classification maps of heterogeneous metropolitan areas.[52] Six bands (1-5 and 7) from an October 28, 1982 TM image, encompassing the Mobile, Alabama metropolitan area, were analyzed and the following land use/cover classes were identified: various forested land cover types; old and new residential single-family dwellings in various densities; apartment complexes, commercial and industrial areas; golf courses; transportation networks paved with asphalt and concrete; grass and water in various conditions; bare ground; and special features (i.e. a coal pile located along Mobile Bay).

Welch reported that the 30 meter spatial resolution of LANDSAT TM and IMS data, permitted the visual interpretation of all level II and III USGS land use/cover classes in Athens, Georgia, with classification accuracies of 70-80 per-

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[52] Wang, S.C. "Analysis Methods for Thematic Mapper Data of Urban Regions," Proceedings 10th International Symposium, Machine Processing of Remotely Sensed Data. West Lafayette: Purdue Research Foundation, 1984. pp. 134-143.

cent.[53] Computer-assisted classification accuracies, however, were approximately 50 percent for level II classes in urban and urban/rural fringe areas.

The following urban area land cover classes are identified in current US Army field manuals as important urban terrain factors, but are not included in the ITADD surface material and transportation factors. General urban classes include:[54] small villages (populations <=1,000); strip areas (interconnecting villages and towns along roads and valleys); towns/small cities (populations > 1,000 but <=100,000 and not part of a major urban complex); and large cities (populations > 100,000 and with an associated urban sprawl > 100 square miles).

Detailed urban classes included: road and street patterns (acute corners, intersections, dead ends, narrow streets, boulevards); open areas (parks, parking lots, playgrounds, cemeteries, large rooftops); central business districts (high rise construction, sewers, subways); and utility line corridors (pipelines, power lines).

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[53] Welch, R. Comparative Assessment of Landsat D MSS & TM Data Quality for Mapping Applications in the Southeast 15 OCT 83-15 JUL 84. Athens: University of Georgia, 6JUN84.

[54] The Tank and Mechanized Infantry Battalion Task Force. Army Field Manual 71-2 JAN 82; FI 71-1/2 MAI 82; 71-1 JUN 77. Washington,DC: US Government Printing Office, pp 5-1-5-31; pp iv-3-26; pp G-1-G-7.

These relatively recent application projects indicate that most, if not all, of the Vegetation, Surface Material, Surface Drainage, and Transportation factors of the TTADB are obtainable using LANDSAT TM data and computer-assisted image processing techniques.

2.3 PROPOSED TTADB CLASSIFICATION SYSTEM FOR USE WITH LANDSAT TM DATA

The following land cover classification system is proposed for the acquisition of vegetation, surface material, surface drainage, and transportation/urban factors of the TTADB using LANDSAT TM digital imagery (see Table 11).

TABLE 11

ITADB Classification System for Use With LANDSAT TM Data

Level I	Level II	Level III
Urban	High Density Urban	Commercial & Services Industrial Industrial/Commerical Complexes
	Transportation/ Communication/ Utilities	All Weather Dual Hard Surface All Weather Hard Surface All Weather Loose Surface Road Bridge Rail Road Rail Yard Railroad Bridge Airfield Utility Corridor
	Low Density Urban	Residential
	Other Urban Land	Parks Cemeteries Undeveloped Land
Agricultural	Cropland/Pasture	Dry Crops Wet Crops Terraced Crops Shifting Cultivation
	Orchard/Groves/ Vineyards Nurseries and Ornamentals Horticultural Areas Confined Feeding Operations Other Agricultural Land	
Rangeland	Herbaceous Rangeland Shrub & Brush Rangeland Mixed Rangeland Bamboo/Cane	
Forest	Deciduous	(percent canopy closure) 0-25 25-50 50-75 75-100

	Evergreen	0-25 25-50 50-75 75-100	
	Mixed	0-25 25-50 50-75 75-100	
Water	Deep Shallow	Lake/Reservoir Stream/River Pond Canal/Ditch/ Channelized Stream	
Wetland	Forested Nonforested	(Swamp) (Marsh/Bog)	
Barren Land	Coarse Grained Soil	GM SM	GC SC
	Fine Grained Soils	ML CL OL PT	MH CH OH
	Dry Salt Flats (Evaporites) Bare Exposed Rock Strip Mines/Quarries Gravel Pits		
Tundra	Shrub & Brush Herbaceous Bare Ground Wet Mixed		
Perennial Snow or Ice	Perennial Snowfield Glaciers		

This system is a modification of the USGS land cover classification system and incorporates most of the detailed factor elements of the ITALL which have been identified in related land cover application projects previously dis-

cussed. This system also possesses the three major attributes of the regional classification process identified by Grigg which include:[55] (1) class names are derived from accepted terminology from both the USAS's classification system and DMA's ITADB classification system; (2) the classification system enables information to be transmitted; and (3) it permits inductive generalizations to be made from one level of detail to another within the hierarchical system.

2.4 DIGITAL IMAGE PROCESSING METHODOLOGY

Digital image processing involves the application of computer-assisted analysis techniques for the display, enhancement, and classification of an array or values acquired by a digital scanner. In the case of LANDSAT digital imagery, the array of values represents the average spectral reflectance (and emittance) of various land cover classes, recorded within the instantaneous field of view (30 x 30 meters for the Thematic Mapper) of the satellite scanning radiometer. Each 900 square meter picture element (pixel) scanned by the satellite's remote sensor is assigned 6 digital numbers (DNs) representing the average spectral reflectance for each of 6 bands (TM bands 1-5 and 7), or segments of the electromagnetic spectrum. A full LANDSAT TM scene contains 41,100,155 pixels per band,[56] representing an enormous data

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[55] Grigg, D."The Logic of Regional Systems", Annals of the Association of American Geographers. Vol.55, No.3, 1965, pp.465-491.

array from which land cover information is derived. The display, enhancement, and classification of land cover categories from multi-band or multispectral digital imagery is a tedious and time consuming process which is readily adaptable to repetitive, quantitative computer manipulation and analysis.

The advantage of machine processing techniques over manual interpretation include:[57] cost effectiveness (less money and time); consistent, quantitative results; the simultaneous interpretation of multi-band, multi-dimensional data; rapid data management, display, processing, and analyses providing input to real time management and policy making decisions; and the effective processing of huge volumes of data.

Disadvantages of computer-assisted processing involve the high initial start-up costs for hardware, software, and digital imagery. However, depending upon the scale of a user's specific project, these costs may be comparable to those associated with conventional data acquisition (air photo missions) and analysis techniques. Other disadvantages include costs associated with formatting the data for compatibility with specific hardware and software systems; preprocessing techniques to correct geometric and/or radiom-

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[56] Tape Format Document for Thematic Mapper. Greenbelt, MD: Goddard Space Flight Center, Jul 1982, pp.5.

[57] Campbell, J.B. Mapping the Land. Washington, DC: AAG, 1983, Chapter 6. pp. 70-71.

etric errors; inflexible image processing software systems which may not readily meet specific user requirements; and quality or accuracy assessment techniques which are not readily understood by users of the land cover information.

There are essentially two tasks involved in the digital image processing of multi-spectral data - data analysis and data classification. Data analysis procedures include preprocessing, feature extraction, and image enhancement.[58]

Preprocessing involves the preparation of the digital data for subsequent analysis by correcting systematic errors induced during data acquisition. This involves correction for errors in image quality (due to atmospheric absorption and/or scattering, and defects in sensor calibration or operation), and image geometry (geographic relationships between image features and ground features). Preprocessing also includes geometric transformation which permits the changing of image scale and projection to approximate the true position of picture elements on the earth's surface.

Feature extraction procedures reduce the dimensionality of the data to a minimal set of useful information without losing essential data. Ideally, feature extraction eliminates "noise" and variables containing little additional information. Examples of feature extraction include data subsets (the best bands for a specific purpose), band ratioing, and principal components analysis.

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[58] Ibid. pp. 73-76.

Image enhancement techniques improve the visual interpretation of spatial distributions of spectral data on digital imagery. Examples of image enhancement techniques include ratioing, thresholding or density slicing, edge enhancement, and contrast stretching.

The thematic classification of multi-spectral data is the second primary purpose of computer-assisted processing of digital imagery. Mausel identified four key terms which are vital to the understanding of computer-assisted thematic classification approaches.[59]

SUPERVISED CLASSIFICATION - a multi-spectral classification algorithm through which the n-dimensional spectral response pattern (spectral signature) of a picture element (pixel) is assigned to a land cover class based on a decision rule when the classes of interest have been defined by a representative training samples of known characteristics (digital numbers or DN's). The algorithm is essentially "trained" to classify pixels according to the spectral signatures associated with specific land cover types designated by a remote sensing analyst.

UNSUPERVISED CLASSIFICATION - a multi-spectral classification algorithm through which the n-dimensional spectral signature of a pixel is classified based on a decision rule that analyzes the spectral characteristics of the data and

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[59] Mausel, P.W. "Characteristics and Techniques of Computer-Assisted Processing of Spectral Data," Holz, R.K. The Surveillant Science: Remote Sensing of the Environment. 2nd Ed. NY: John Wiley & Sons, Inc. 1988. pp. 244-301.

Figure 2: Farrington, North Carolina

TABLE 13

North Carolina Piedmont TM Data Subset

APPLEPITS BAND	TM BAND	WAVELENGTH (um)	RANGE
1	2	0.45-0.52	Green
2	4	0.76-0.90	Near IR
3	5	1.55-1.75	Middle IR
4	7	2.08-2.35	Middle IR

tilinear grid of 230 x 192 pixels representing approximately 5.4 x 5.76 kilometers at a scale of 1:24,000 (approximately 49 square KM). Table 12 describes the geographic dimensions of the three NC Piedmont Applepips images .

TABLE 12

North Carolina Piedmont APPLEPIPS TM Images

IMAGE	CORNERS	LATITUDE North	LONGITUDE West
FAYETTEVILLE	NW	35 49'12"	79 5'29"
	SE	35 46'16"	79 0'11"
NEW HILL	NW	35 43'41"	78 53'42"
	SE	35 39'25"	78 55'42"
CHAPEL HILL	NW	35 57' 0"	79 0'29"
	SE	35 52'44"	79 2'55"

The three Piedmont study area data sets contain only four of the original seven TM bands. These data subsets represent the TM bands identified by previous land cover application projects which permit the accurate classification of land cover categories which are potentially militarily significant. Table 13 includes the four LANDSat TM bands used in this Piedmont land cover mapping study.

Figures 2, 3, and 4 depict the dimensions of the three study areas at an original scale of 1:24,000.

range; and the mathematical transformation of the data into a Space Oblique Mercator projection. The format of the TM data was band sequential, 1600 BPI computer compatible tape (CCT), one TM band per tape for a total of seven CCT's.

In order to analyze and classify the TM data with the Apple Personal Image Processing System, additional preprocessing steps were necessary. These steps consisted of reformatting the initial CCT data set to a 5 1/4 inch floppy disk format, compatible with the Apple II series microcomputer.

The reformatting or downloading procedure was completed by the Nebraska Remote Sensing Center (NRSC), Conservation and Services Division, University of Nebraska at Lincoln. A 7 1/2' map-image was extracted for each of the three Piedmont study areas, and geo-encoded to its respective 7 1/2' USGS topographic map sheet using NRSC's Home and Office Techniques for Local Image Processing System (HOTLIPS).[71] The geo-encoding calibration procedure accurately registers the digital image to a topographic map within + or - 1 pixel and can be easily adapted to other map scales (1:250,000, 1:25,000, 1:50,000).

Due to the Apple II Series color monitor limitations, the largest area that can be displayed for analysis and classification is a 280 column x 192 row digital image. Therefore, the final downloaded TM data format consists of a rec-

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[71] Miller, L.D. et.al. " 7 1/2' map-image Extraction from Precision Processed LANDSAT MSS and TM Imagery Using a Microcomputer and USGS Computer Compatible Tapes," Lincoln: Nebraska Remote Sensing Center, 1986.

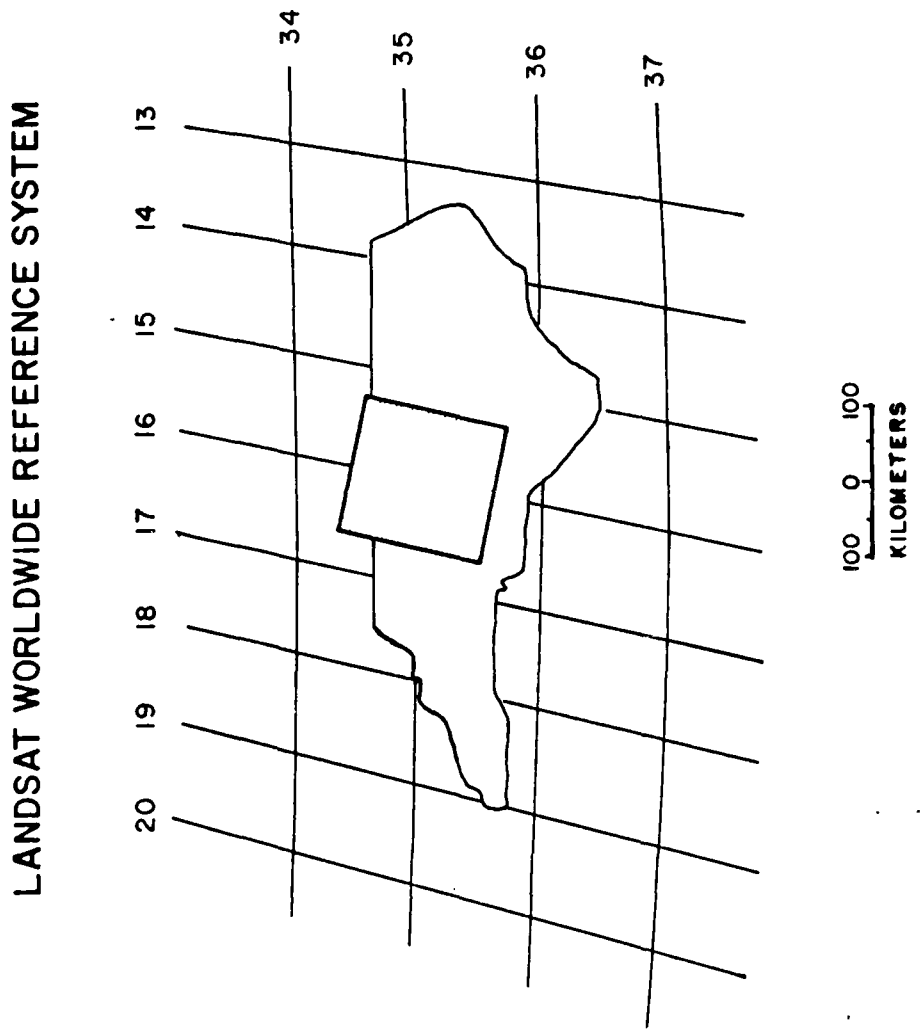

Figure 1: WRS Path 16 Row 35

Chapter III

DATA AND STUDY AREA DESCRIPTION

3.1 PRIMARY DATA DESCRIPTION

The primary data for this land cover study were seven full scene LANDSAT 4 Thematic Mapper computer-compatible tapes, #40116-15211, World Reference System (WRS) Path 16, Row 35, with an acquisition date of November 9, 1982. As of this writing, five other TM scenes for Path 16 Row 35 have been acquired, however, the November 1982 image is the only one available with less than 20 percent cloud coverage.[70] The acquisition date corresponds to the Fall period recommended in previous land cover projects as one of the best seasons of the year for differentiating land cover classes in the southeastern U.S. Figure 1 illustrates the geographic location of WRS Path 16, row 35.

The TM data set was preprocessed by NOAA's Image Generation Facility using the Scrounge processing system. Preprocessing included geometric error correction to within 0.5 sensor pixel (90 percent of the time); temporal registration to within 0.5 sensor pixel (90 percent of the time); radiometric error correction within 1 quantum level over the full

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[70] Kaevoka, P.V. "Availability of LANDSAT 4 TM Data" Technical Papers 50th Meeting American Society of Photogrammetry. Falls Church: ASP, 1984, V2. pp. 464-471.

The stratified systematic unaligned sampling technique will be used to locate the ground truth samples on the land cover maps for classification accuracy determination. The resulting sample combines the advantages of randomization, stratification, the useful aspects of a systematic sample, and provides an accurate unbiased sample since there are no periodicities in the data that interact with the systematic spacing of the samples.[69]

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[69] Berry,B. and Baker,A."Geographic Sampling", Spatial Analysis. NJ: Prentice-Hall Inc.1968,pp.94.

cover classification of the N samples, as depicted on the land cover map produced from remote sensor data, is checked against that observed on the ground. The map is accepted as accurate if no more than X of the ground truth samples are misclassified. This technique assumes that the land cover classification of a particular site is either correct or incorrect.

This method is based on a branch of statistics known as acceptance sampling, a statistical procedure for determining if large lots of manufactured articles (ground truth samples) are of acceptable quality (correctly classified). Using the binomial probability density function (p.d.f.),[67] Ginevan calculated and compiled extensive tables of minimum sample sizes and error counts given typical values of the four parameters. Using the USGS' minimum acceptable accuracy standard, Q2 = 85 percent; a target accuracy, Q1 = 95 percent; and the probability of rejecting a map of high accuracy or accepting a map of low accuracy, $\alpha = 0.05$; $\beta = 0.05$, he determined a minimum sample size of N = 93 ground truth samples were needed. If no more than 8 ground truth sample sites were misclassified the land cover map could be accepted as 85-95 percent accurate at the 0.05 confidence level.[68]

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[67] Ibid. pp.1574.

[68] Ibid. pp.1573.

Several site specific accuracy assessment techniques have been developed for use with land cover maps prepared from remote sensor data. The technique selected for use in this study provides an accuracy assessment of both the control point location accuracy and polygon classification accuracy.[66]

This technique, designed by Ginevan, requires the specification of four parameters : (1) the target accuracy, Q1 (the probability that a point is correctly classified); (2) a minimum acceptable accuracy, Q2; (3) the probability of a Type I error, a (alpha - the probability of rejecting a map that meets or exceeds the standards but by chance the sample tested contains enough errors to reject the map); and (4) the probability of a Type II error, B (beta - the probability of accepting a map that does not meet the standards but by chance the sample tested is accurate enough to accept the map).

Ginevan's method improved upon previous accuracy assessment techniques by determining the minimum number of ground truth samples (N) and an allowable number of misclassifications (X) for specific target and minimum acceptable accuracies (Q1 and Q2) and confidence limits (a and B). The land

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fication System for Use with Remote Sensor Data," USGS Professional Paper 964, Washington, DC: US Government Printing Office, 1976, pp. 4.

[66] Ginevan,M.E. "Testing Land-Use Map Accuracy: Another Look", Photogrammetric Engineering and Remote Sensing, Vol.45,No.10,Oct. 79,pp.1371-1377.

delity of the image (map projection and control point accuracy).

Polygon classification accuracy refers to the ability of the map to accurately represent the landscape by determining if each category in a classification is really present at the points specified on the map. Classification accuracy is determined using site specific or non-site specific techniques.[64]

Non-site specific techniques involve the matching of classified polygons between a 'standard' map superimposed on the map produced from remote sensor data. The areal proportins of the two maps that match are reported as a percent of agreement (i.e. 90%). This technique provides only an overall, general accuracy assessment.

Site specific techniques involve the determination of a unit of comparison (i.e. 1 pixel; 100x100 meters) and the comparison of the category depicted on the map with the same areal unit located on the ground or on some 'standard' ancillary reference (air photo; existing land cover map).

The classification accuracy standard for the USGS land cover/land use map series is a minimum acceptable accuracy of 85 percent at the .05 confidence level (or 85 percent of the polygons on the choropleth map are correct 95 percent of the time) for the level I and II land cover categories.[65]

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[64] Campbell, J.B. Mapping the Land. Washington, DC: AAG, 1983, pp. 84.

[65] Anderson, J.R. et.al. "A Land Use and Land Cover Classi-

little generalization occurs in scenes with large, uniform land cover parcels (i.e. forests, wheat fields) even with the lower resolution of MSS data. Small, heterogeneous land cover parcels (i.e. urban areas, urban fringe areas) become highly generalized even with the Thematic Mapper's 30 meter resolution.

Data processing errors are of three types: control point location error; boundary line error; and polygon classification error.[62] United States national map accuracy standards for ground reference points require not more than 10 percent of tested points to be more than 1/50 inch in error for mapping scales smaller than 1:20,000.[63] At 1:24,000, the scale used for this project, that standard equates to approximately 12 meters on the ground. The geometric registration of the LANDSAT TM data used in this project (discussed in the following chapter) is approximately 30 meters.

Boundary line error refers to the accuracy of divisions between land cover categories represented on the map with respect to those same boundaries on the ground. Boundary line delineation is affected by the homogeneity of land cover classes and their naturally occurring gradational boundaries, the resolution of the remote sensor, and the cartographic distraction that occurs during map production. Boundary line accuracy is also affected by the geodetic ri-

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[62] Bozier, J. and Strahler A.H. "Ground Investigation in Support of Remote Sensing" ibid. Chap. 23, pp. 982.

[63] ibid.

2.5 ACCURACY ASSESSMENT METHODOLOGY

The accuracy of a thematic land cover map produced from either the landscape or quantitative approach to terrain evaluation is dependent upon three possible sources of error, data acquisition, data processing, and scene dependent error.[60]

Radiometric and geometric data acquisition errors are corrected during the preprocessing of LANDSAT digital imagery by NOAA's Image Generation facility to meet the LANDSAT 4 systematic error correction standards. Assessment of these preprocessing error corrections is beyond the scope of this project and, therefore, it will be assumed that the preprocessing of the November 9, 1982 image met the LANDSAT 4 system geometric and radiometric standards (band to band geometric registration within 0.5 pixel, 90 percent of the time; temporal registration to within 0.3 pixel, 90 percent of the time; and radiometric error correction within one quantum level).[61]

Scene dependent error refers to the amount of generalization that occurs as a result of the spatial resolution of the remote sensor and the size, homogeneity, and spatial distribution of land cover in a particular geographic area.

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[60] Short, N.M. The LANDSAT tutorial workbook. NASA Reference Publication 1078. Washington, DC: NASA Scientific and Information Branch, 1982, Chap. 6, pp. 248.

[61] Fredden, S.C. and Gordon, F.J.B. "LANDSAT Satellites," Manual of Remote Sensing. Falls Church, Va: American Society of Photogrammetry, Chap. 12, pp. 501.

[illegible] data) into user specified land cover classes based on analyst defined representative ranges or spectral responses or signatures (the minima and maxima DN values observed from representative samples of known land cover classes for each band in the data set). Most minicomputer and microcomputer systems have nonparametrically based classification algorithms because of their relatively good classification results which are quickly and inexpensively produced.

The nonparametric supervised PPD approach permits the complementary use of both the landscape and quantitative approaches to terrain evaluation. Training samples from specific land cover types of interest must first be identified on aerial imagery and/or topographic maps and then identified on a hard copy or color monitor display for each band in the data set in order to develop the n-dimensional spectral signature for each land cover class. This requires digital image analysts to be familiar with both conventional image interpretation techniques used in the landscape approach, and the techniques for identifying relevant parameters or attribute values which separate land cover classes of interest, as well as the computer-assisted enhancement and classification techniques used in the quantitative approach to terrain evaluation.

[illegible] of clusters spectral values that are close together, without regard to the environmental objects that reflect the [illegible] data. In this approach, known spectral signatures of classes are determined through a training sample approach or [illegible].

[illegible] ALGORITHM - a computer algorithm used to develop a decision rule for the classification of n-dimensional spectral response data of known character. In this algorithm, the data is assumed to have a normal distribution which permits the classification of pixels based on the statistical probability that a given spectral signature is associated with a specific land cover class.

NONPARAMETRIC ALGORITHM - an algorithm used to develop a decision rule for the classification of n-dimensional spectral response data that does not assume normality or require data to be distributed in any particular form. This algorithm uses biased samples from the spectral data that are empirically derived, representing spectral response patterns of known cover classes, and are not suitable for probability analysis.

The Apple Personal Image Processing System (APIPPS) classification algorithm is based on a nonparametric supervised approach to multi-spectral classification. This approach, known as a look-up table or parallelpiped approach (LUT), is very cost effective, requiring only the [illegible] of n-dimensional spectral data (n=3 or 7 for LANDSAT

Figure 3: New Hill, North Carolina

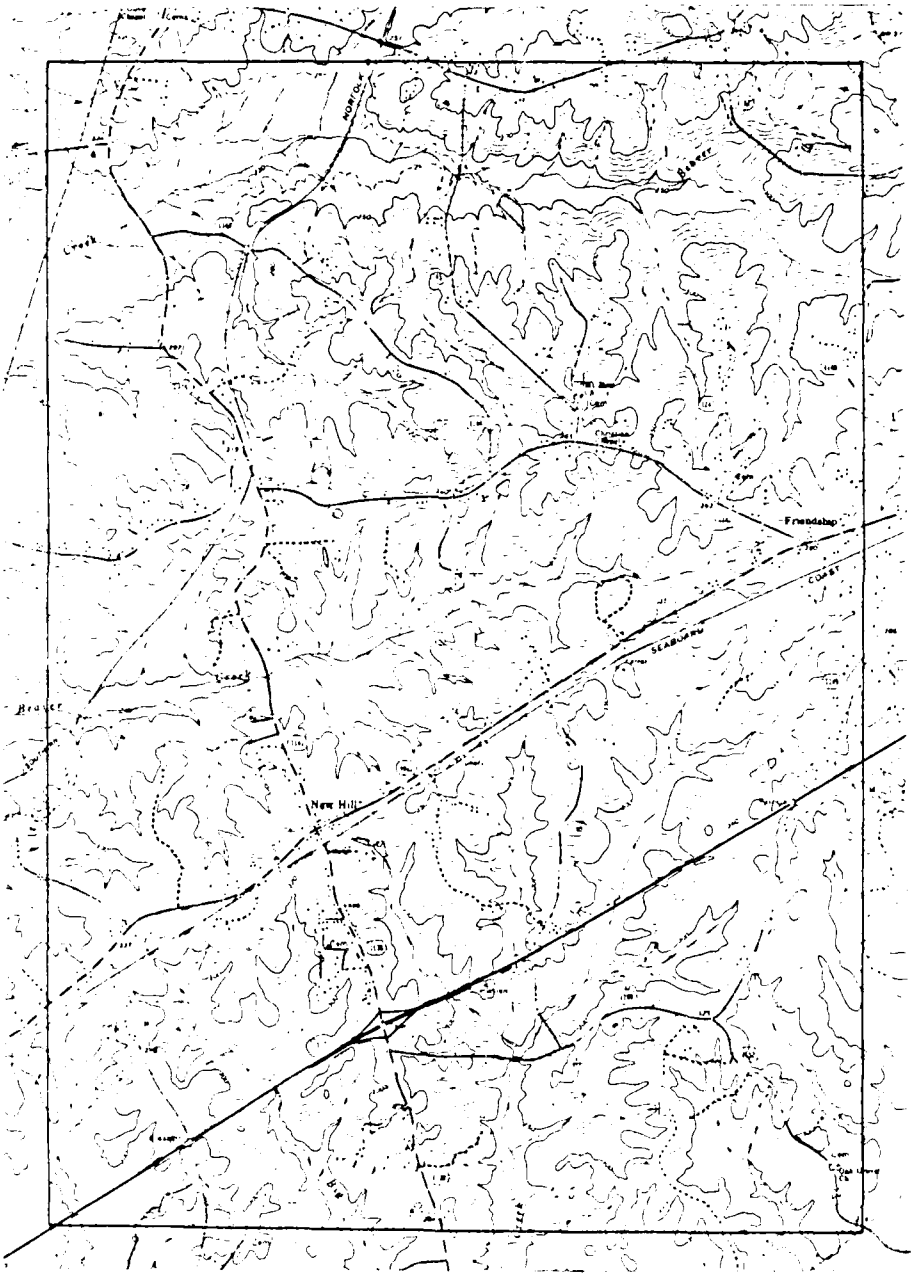
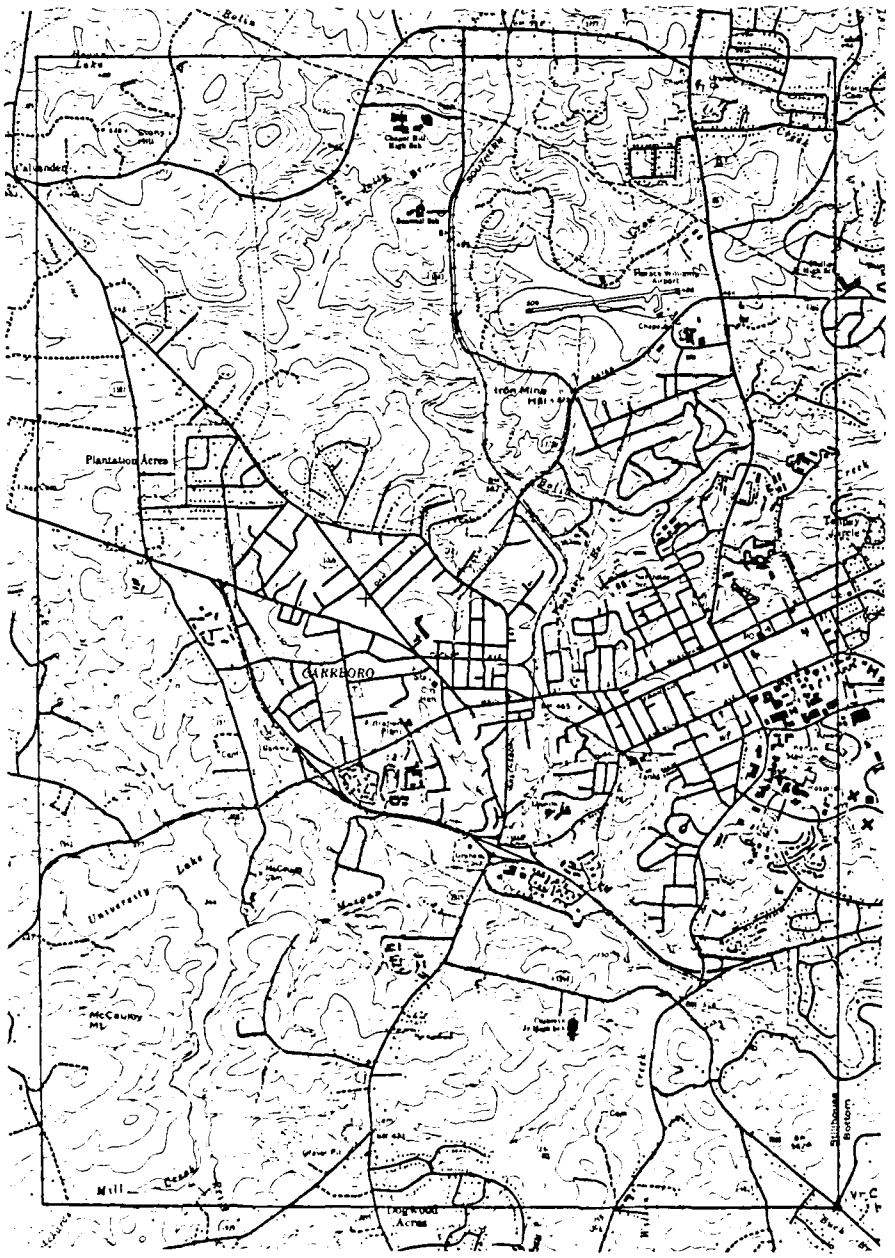


Figure 4: Chapel Hill, North Carolina



3.2 ANCILLARY DATA DESCRIPTION

Ancillary reference data used for analysis, classification, and accuracy assessment included USGS topographic and land use maps; NOAA daily weather maps; black and white and color infrared aerial photographs and mosaics; a 40 inch IrCS false color IR image of the original TM data set; USDA county soil surveys and soil maps; and direct field observations during the periods October-December 1984 and January-March 1985. Table 14 list the ancillary references used in the land cover study.

TABLE 14

Piedmont Land Cover Study Ancillary References

FORMAT	SCALE	DATE
USGS Topographic Maps		
Farrington, NC	1:24,000	1981
New Hill, NC	1:24,000	1981
Chapel Hill, NC	1:24,000	1981
USGS Land Use Map		
Raleigh, NC	1:250,000	1972
USDA Soil Maps		
Chatham County, NC	1:250,000	1975
Wake County, NC	1:15,840	1907
Orange County, NC	1:20,000	1972
NC Geologic Maps		
Durham Area	1:300,000	1966
Orange County	1:62,500	1968
Wake County	1:100,000	1979
Imagery		
LFOS Path 16 Row 35 False Color Composite	1:220,000	9 NOV 82
NHAP Color IR	1:60,000	12 APR 83
NHAP Color IR (Chapel Hill only)	1:68,000	12 APR 83
NHAP Panchromatic	1:60,000	12 APR 83
ASCS Panchromatic	1:40,000	16 NOV 75
ASCS B&W Mosaic	1:40,000	
Chatham County, NC		7 NOV 79
Wake County, NC		27 APR 81
Orange County, NC		16 NOV 75

3.3 STUDY AREA DESCRIPTION

The three study areas selected for this project are representative of typical agricultural, forested, and urban land covers found in the Piedmont physiographic region.

The physical landscape of the Piedmont reflects the geo-

logic structure and climate of the region.[72] The geologic structure consists of ancient eugeosynclinal sedimentary deposits which have been metamorphosed, intruded, faulted, and deeply weathered in a mild, humid (mesothermal) climate. Most of the rocks in the region are gneiss and schist with some marble and quartzite. The Carolina Slate Belt, consisting of less intensively metamorphosed rocks, occurs along the eastern portion of the Piedmont from southern Virginia to Georgia, comprising approximately 20 percent of the region. Igneous intrusions, consisting of granites, granite gneiss, and gabbro form resistant uplands. Sedimentary rocks in the Triassic basin make up the remaining 5 percent of the region. These rocks consist of sandstones, conglomerates, and silts intruded by diabase dikes and sills.

Surface materials in the Piedmont consist of Pleistocene age alluvium, late Pleistocene and Holocene age colluvium, and ancient, deep residual soils termed saprolite. Although soil materials are directly related to the parent rock material, the following soil horizon description is characteristic throughout the Piedmont. The A-horizon, a thin layer of organic material 1-2 inches thick over a slightly leached, light colored layer 1-2 feet thick, overlying an illuviated, clayey B-horizon 2-3 feet thick. The C-horizon consists of a massive clay and structured saprolite (sesqui-

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[72] Hunt, C.B. Natural Regions of the United States and Canada. San Francisco: W.H. Freeman and Co. 1974, Chap. 11, pp. 295-305.

oxides), more than 100 feet thick in places. The underlying parent material usually consists of a zone of weathered rock over unweathered parent rock.

The natural vegetation of the region is classified as mixed oak/pine and southeastern pine forest. The plant geography often reflects the topography and subsurface geology.[73] Typically, forested Piedmont upland areas (clayey residuum over bedrock) consist of Oak (White, Black, Chestnut, Red Oaks), Yellow poplar, and Pine (Virginia, Shortleaf, White, Yellow); flood plains (alluvium over bedrock) consist of primarily deciduous trees (Sycamore, Elm, Box Elder, Silver Maple, River Birch); and swamp areas (wet ground over bedrock) consist of Maples, Oaks (Pin, Swamp White, and Willow Oaks), and Sourgum.

Agriculture in the region occurs on cleared uplands and floodplains with severe soil erosion occurring on slopes greater than 15 percent without terracing. General farming, dairying, livestocking, and cash cropping (tobacco) are the primary agricultural activities in the Piedmont.

The surface drainage pattern of the Piedmont is dendritic, characteristically found on thick, horizontally deposited sediments. Few large natural lakes occur in the region, although numerous large man-made lakes and reservoirs have been created over the past several decades. Numerous small man-made lakes and farm ponds dot the landscape.

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[73] Ibid., pp. 242.

The climate of the Piedmont region is relatively mild and humid with rarely occurring extreme weather conditions. Average annual temperature extremes are from the low 70's F to the upper 40's F range. Average monthly precipitation totals 40-45 inches per year and the average annual soil temperature is 60 F. The average growing season runs from the second week in April to the last week in October, approximately 200 days. Much of the precipitation in the growing season is the result of summer thunderstorm activity. Winter precipitation results mainly from low-pressure storms moving through or near the region. Average monthly snow accumulation rarely exceeds two inches.[74]

Table 15 lists the daily weather conditions reported by the Raleigh weather station from November 2-10, 1982, the week prior to and including the LANDSAT TM data acquisition date.[75]

The average daily temperature was approximately 2 degrees F above the thirty year mean and monthly precipitation was 75-100 percent of the normal amount expected.[76]

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[74] Soil Survey of Wake County, NC. Washington, DC: USDA National Cooperative Soil Survey, 1970. pp. 113-116.

[75] US Department of Commerce Daily Weather Maps. Washington, DC: US Government Printing Office, 1-7NoV82 and 8-14NoV82.

[76] Quinlan, D.M. "Weatherwatch", Weather Wise. Washington, DC: Heldref Publications Vols. 36, No. 1, Feb. 1983. pp. 37-41.

TABLE 15

Study area daily weather conditions 2-10 November 1982

DATE	*1200 F	**HIGH / LOW		**Precipitation (inches)
2NOV	62	75	60	-
3NOV	53	76	51	-
4NOV	69	80	67	-
5NOV	40	80	39	.60
6NOV	43	52	27	-
7NOV	27	51	37	-
8NOV	30	59	28	-
9NOV	36	67	35	-
10NOV	42	71	41	-

* Daily Report as of 0700 EST
** Previous 24 Hour Period

A cold front passed through the general study area November 4-5. A high pressure system dominated weather conditions November 6-10, permitting ideal, virtually cloud free data acquisition conditions.

The descending node of LANDSAT 4's orbit crosses the equator at approximately 0945 local sun time, resulting in the acquisition of Path 16 Row 35 at approximately 0940 EST. The sun elevation angle and azimuth at acquisition were 32 and 151 degrees respectively.

The only adverse effect of the weather conditions at the time of data acquisition was the amount of precipitation during the week prior to acquisition. Although almost an inch of rain fell in the general area, the high permeability of the soils (ranging from 0.6-2.0 inches/hour) and their relatively low available water capacity (ranging from

0.10-0.20 inches/inch for coarse grained soils; 0.14-0.20 for fine grained soils), combined with a 3 day relatively cloud free period (temperature reaching the upper 50-60 F range), resulted in a relatively low soil moisture content. Hoffer reported similarities in infrared spectral reflectance levels for soil materials and man-made surface materials (concrete, asphalt, building materials) with relatively low moisture contents, which made differentiation between soil and man-made surface materials difficult.[77]

The following paragraphs provide a general description of the landscape and land cover of the three Piedmont study areas used in this land cover mapping project.

3.3.1 Farrington, North Carolina

The Farrington study area is located in northeastern Chatham County, approximately 10 miles northeast of Pittsboro, the county seat. The area encompasses approximately 40 square kilometers (6.4 x 5.76 km) adjacent to and due west of B. Everett Jordan Lake.

The topography of the area consists of rolling, forested hills with slopes generally not exceeding 30 percent. The maximum relief in the area is 400 feet, with a northeast to southwest trending ridge in the center of the study area.

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[77] Hoffer, R.M. "Biophysical Considerations in Applying Computer-Aided Analysis Techniques to Remote Sensor Data," Davis, S.M. and Swain, P.H. Remote Sensing the Quantitative Approach. NY: McGraw-Hill Inc., 1978, Chap 5. pp. 249-252.

The upland surface generally slopes to the southeast and is dendritically dissected by southeast and northeast flowing antecedent streams.

The drainage pattern in the area is dendritic, consisting of intermittent and perennial streams draining into the former New Hope River Valley. Construction of the B. Everett Jordan dam in 1979 drowned the New Hope River valley and its tributaries to an average level of 215 feet. The drowned valley of Bush Creek, located in the north central portion of the area, forms a low wetland forest and swamp. Numerous small man-made farm ponds are scattered throughout the study area.

Most of the Farrington study area is underlain by a metavolcanic unit of pyroclastics, flows, and interbedded sedimentary rocks. The metavolcanic unit grades upward into a predominantly sedimentary unit consisting of argillite, slate, graywacke, sandstone, graywacke conglomerate and tuff. The sedimentary rocks are overlain by andesitic tuffs and flows of the mafic tuff and flow unit. These three rock units have been intruded and locally metamorphosed by igneous plutons of granite to granodiorite composition, the largest being Edwards Mountain located just north of the study area.[78]

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[78] Daniel, C.C. "Geology and Ground-water in the Durham Area, NC", Ground-Water Bulletin No. 7, Washington, DC: USGS, May 1988, pp.66.

Surface soil materials consist of silt, clay, and sandy loam of yellowish brown, yellowish red, or light gray tones. Soil materials are only exposed in plowed/barren agricultural fields, road cuts, and along the lake shore.

The predominant vegetation in the study area is evergreen and deciduous forests. Evergreen trees include coniferous holly, shortleaf, Virginia, and Eastern white pine, generally located in reforested pine plantation areas. Deciduous trees include the Oak, Cottonwood, walnut, Ash, Sycamore, Yellow poplar, and Sweet gum. These are generally found on steeper slopes and in stream valleys.

Agricultural row crops grown in the study area include corn, soybeans, and tobacco. Close grown crops include wheat, barley, and oats. Clover, fescue, orchard grass, and lespedeza provide forage in the pasture areas. Due to the image acquisition date, the only crop under cultivation was spring wheat. Pasture areas and deciduous trees were also senescent at the time the data was acquired.

The transportation network in the study area consists of single lane, all weather, macadam or asphalt hard surface roads. Improved, all weather, loose surface gravel and unimproved, all weather sand/clay surface roads connect farmsteads to the major road network. An earth/stone causeway with a concrete bridge on state road 1008 crosses Jordan Lake in the eastern portion of the study area. An east-west oriented cleared pipeline corridor consisting of grass and

scrub vegetation, traverses the southern portion of the area.

Urban areas in the Farrington image consist of only the rural non-farm residential community of Fearington, located on the northwest edge of the study area. This community generally consists of single family dwellings with tree covered lots. The remainder of the population within the area lives in rural farm strip settlements located along the road network.

The Farrington image was selected primarily to evaluate the classification of the vegetation categories of the FLADR. Other categories evaluated included water, urban, agricultural, and transportation classes.

3.3.2 New Hill, North Carolina

The New Hill study area is located in western Wake County, approximately 18 miles southwest of Raleigh, the state capitol. The area encompasses approximately 48 square kilometers (8.4 x 5.76 km; 280 x 192 pixels), due east of B. Everett Jordan Lake.

The topography of the area reflects the geologic structure, a Triassic age geologic basin. The gently rolling, forested and cultivated lowland is submaturely dissected by west, northwest, and southwest flowing antecedent streams north of state road 1011. South of 1011, which was constructed on the stream divide between the New Hope and the

ape Fear River drainage basins, streams flow south, southeast and southeast. Upland surfaces slope gently to the southeast.

The drainage pattern in the area is dendritic, consisting of intermittent and perennial streams, tributaries of the former New Hope River in the north (now flowing into Jordan Lake) and several small streams in the southeast (now flowing into Sharon Harris Lake, a cooling reservoir for the Sharon Harris Nuclear power plant currently under construction just south of the study area). The drowned valleys of Beaver Creek and Little Beaver Creek form swampy, forested standing areas during periods of high lake levels (>220 feet). Numerous small man-made lakes and farm ponds dot the landscape, as well.

The geology of the New Hill study area is described as Triassic basin sedimentary rocks of the Newark group.[79] Formations in this group identified in the study area include conglomerates (metamorphic and igneous rock clasts in a red-brown clay-silt-sand matrix interbedded with mudstone and sandstone) generally located in the east and southeast portion of the study area; sandstone-mudstone deposits (red mudstone and calcareous sandstone deposits with thin layers of impure gray limestone and lenses of gray chert or red-brown jasper) located in the west and northwest portion of

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[79] Park, J. C. "Geology and Mineral Resources of Wake County," Geological Survey Bulletin No. [illegible]. Raleigh: [illegible] Dept. of Natural Resources, 197[illegible], pp. 7[illegible]-[illegible].

study area; and diabase dikes (medium-grained dolerite) ich have intruded the sedimentary formations. Other sedi-tary rocks in this formation include flood plain and ream terrace alluvium and colluvium at lower elevations. Surface soil materials consist of sand, clay, and silt ed particles mixed with organic matter. Typical Piedmont il horizons are found with depth to bedrock varying be-een 10 and 60 feet. Table 16 lists the surface soil ma-rials found in the New Hill study area.[50]

TABLE 16

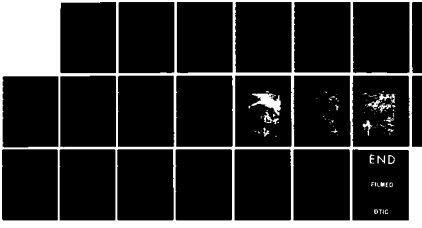
New Hill Surface Soil Materials

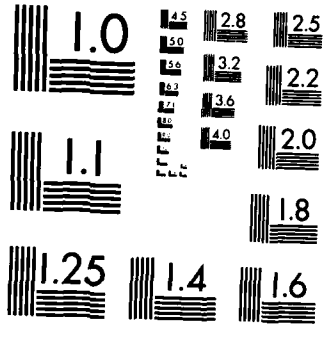
SOIL SERIES	USCS	PARENT MATERIAL
Triassic sediments:		
Creedmore	SM	Sandstone
Granville	SM	Siltstone
Mayodan	SM,GM	Mudstone
Pinkston	SC,SM	Claystone
Whitestone	SM	Shale
		Conglomerate
Floodplain alluvium:		
Buncombe	SM	
Chewacla	ML,SM	Fluvial sediments
Congaree	SM,SC	
Kenhadkee	ML	
Stream alluvium:		
Altavista	[illegible],ML	
Augusta	SM,ML	Fluvial sediments
[illegible]	[illegible],ML	Colluvial sediments
[illegible]	ML,SM	

[illegible]

AD-A154 781 MICROCOMPUTER PROCESSING OF LANDSAT THEMATIC MAPPER DATA FOR THE ACQUISIT..(U) ARMY MILITARY PERSONNEL CENTER ALEXANDRIA VA S J MCGREGOR 12 APR 85 2/2

UNCLASSIFIED F/G 8/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Deciduous and evergreen second-growth natural and man-stocked forest is the dominant vegetation cover in the study area. Loblolly, Shortleaf, White and Yellow pine plantations are the dominant forest type with Oak, Cottonwood, Ash, Sycamore, Poplar, Walnut and Sweet gum deciduous trees found in stream valleys and on steeper slopes.

Agricultural row crops grown in the area include corn, tobacco, and soybeans. Close grown crops include oats and wheat. Lespedeza, fescue, and white clover are grown as pasture cover. Due to the data acquisition date, spring wheat was the only crop under cultivation. Pastures and deciduous trees were also senescesed.

The transportation network in the New Hill study area consists of single lane, all weather, macadam, asphalt, and concrete hard surface roads. Improved, all weather, loose surface gravel and unimproved, fair weather sand/clay surface roads connect farmsteads to the main road network. Concrete highway bridges and interchanges are located on US 1, which runs northeast-southwest in the southern portion of the study area. State road 1011 parallels US 1, in the center of the area, with a multiple and single track section of the Seaboard Coast Line railroad, just south and adjacent to the county road. A concrete bridge also spans Beaver Creek in the northwest portion of the area.

Urban areas include the small rural towns of New Hill and Friendship located on state road 1011 in the center of the

study area. The remainder of the rural population lives in strip settlements adjacent to the road network.

The New Hill image was selected primarily to evaluate the classification of surface material and transportation categories of the ITADB. Other categories evaluated included water, forest, agriculture, and wetland.

3.3.3 Chapel Hill, North Carolina

The Chapel Hill study area is located in southeastern Orange County, approximately 10 miles southeast of Hillsborough, the county seat. The area encompasses approximately 48 square kilometers (8.4 x 5.76 km), northwest of B. Everett Jordan Lake.

The topography is typical of the Piedmont region with gently rolling uplands, rounded hills, and V-shaped valleys with slopes generally not exceeding 30 percent. The maximum relief in the area is 330 feet, with upland surfaces sloping gently to the southeast. The topography is submaturely dissected by south, southeast, northeast, and east flowing antecedent streams.

The dendritic drainage pattern flows generally in the east-southeast direction as first and second order tributaries of the former New Hope River, now Jordan Lake. University Lake, a large man-made reservoir in the drowned valley of Morgan Creek is located in the southwest corner of the study area. Numerous small man-made lakes and farm ponds are scattered throughout the area.

The geology of the Chapel Hill study area consists of pyroclastic and flow rocks of dacitic to rhyolitic composition (lowlands) and intrusive igneous complexes (uplands).[81] The igneous plutonic rocks include granite, quartz monzonite, granodiorite, diorite, and gabbro. An ultra mafic body, composed of dark, coarse grained hornblende, olivine, and magnetite occurs at Iron Mine Hill, southwest of Horace Williams Airport.

Surface soil materials consist of a light red clay, silt, and sandy loam. Typical Piedmont soil horizons are found with depth to bedrock ranging from approximately 20-80 feet.[82] Parent materials include igneous and volcanic rocks and alluvial/colluvial sediments on floodplains and terraces.

The predominant vegetation in the study area is evergreen and deciduous forest. Cleared upland areas on the outskirts of Chapel Hill and Carrboro are cultivated row and close grown crop fields and pastures. Spring wheat is the only crop under cultivation on the TM image. Pastures and deciduous trees are senesced with other crop fields lying fallow. Most of the residential housing in the area are covered by dense deciduous and evergreen trees.

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[81] Allen, E.P. and Wilson, W.E. "Geology and Mineral Resources of Orange County, NC", Bulletin 81. Raleigh: NC Dept. of Conservation and Development, 1968, pp. 7-25.

[82] Soil Survey of Orange County, NC Washington, DC: USDA National Cooperative Soil Survey, 1977, pp. 85-86.

The transportation network in the Chapel Hill area includes single and multiple lane, all weather, macadam or asphalt hard surface roads. Improved, all weather, loose surface gravel and unimproved, fair weather sand/clay surface roads connect rural farm and rural non-farm areas to the main road network. Concrete bridges and interchanges are located on the main roads. A single track spur of the Southern railroad oriented north-south terminates in downtown Chapel Hill. Horrace Williams Airport, with a 3,500 ft. macadam surface runway oriented east-west, is located in the northeast portion of the study area. A pipeline corridor oriented northwest-southest and a transmission line corridor oriented north-south are also located north and west of Chapel Hill.

Major urban areas include the town of Chapel Hill; University of North Carolina; and Carrboro. Urban land cover categories include residential; commercial and service; institutional; transportation, communications, and utilities; industrial and commercial complex (extractive); and mixed or other built-up land.[83]

The Chapel Hill image was selected primarily to evaluate the classification of transportation categories of the ITADB and the additional urban land cover classes identified as critical urban terrain conditions in current Army field manuals. Other categories evaluated included forest, water,

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[83] "Land Use and Land Cover Map, 1972" Raleigh, NC 1:250000. Reston, VA: USGS, 1982.

and agricultural classes.

Chapter IV

DATA ANALYSIS, CLASSIFICATION, AND ACCURACY ASSESSMENT

4.1 SUPERVISED NONPARAMETRIC CLASSIFICATION METHODOLOGY

Militarily significant land cover categories were classified for each of the three Piedmont study areas, using the proposed IIADB classification system for use with LANDSAT TM data and the supervised nonparametric classification approach of the Apple Personal Image Processing System.

This approach requires the image analyst to identify a characteristic spectral response pattern, or spectral signature, unique to each land cover class of interest. This spectral signature is based on the minimum and maximum reflectance values, DN's, observed from representative samples of known land cover categories, for each band or channel in the data set. These samples or training sites, chosen by the analyst, represent biased samples which are not suitable for probability analysis techniques that assume normality. Based on the empirically derived signatures, selected bands in the data set were classified as to nominal land cover categories using the Applepips' parallelepiped (PPD) classification algorithm.

The PPD classification algorithm determines which pixels fall inside an n-dimensional classification space, defined by the n-dimensional spectral limits (minima, maxima) of a particular land cover's spectral signature. The computer searches each pixel in the multi-band data set and determines which pixels fall within the maxima and minima for each class. Pixel DN values which fall within the classification space are classified and identified with a number corresponding to the order in which the signatures were entered in the signature training routine. Unclassified pixels are assigned a value of zero. The algorithm permits multiple classification iterations and expands signature intervals based on a user specified amount. The percentage of the image classified in each land cover category and the number of pixels in each category are reported and the classified image is stored as a separate band on disk for later display or further analysis.

4.2 FEATURE EXTRACTION

The feature extraction techniques used in this study include subsetting and principal component analysis (PCA). Only four of the original seven TM bands were downloaded from the CCT to the 5 1/4 inch floppy disk format. This subset, TM bands 2, 4, 5, and 7, represents those thematic mapper bands identified in previous band cover application projects which resulted in accurate land cover classificatin of categories which are of potential military significance.

PCA was also used to create a fifth data band for analysis and classification. PCA decomposes the total variation of a multivariate data set into linearly independent components of decreasing magnitude. The first principal component, which contains most of the variation (information) found in the four original TM data bands, has been identified as a vegetation sensitive indicator in previous land cover studies.[84]

The APPLEPIPS spectral transformation subroutine, Eigenpictures, calculates a correlation matrix using the four TM data bands for each quadrant (northwest, northeast, southwest, southeast) of a PIPS TM image. Coefficients of determination (R squared) values are reported and the eigenvector coefficients for each band are calculated for each of the four principal components.

By multiplying pixel DN values in each band by its corresponding vector weight and summing the products, a fifth band was created, the first principal component band.

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[84] Short, N.M. The LANDSAT tutorial workbook. Washington, DC: NASA Scientific and Technical Information Branch, 1982, pp. 17o. and Quattochi, D.A. etal. "An Initial Analysis of LANDSAT 4 TM Data." NASA Report No. 215. NSTL Station MS: NASA, Nov 1982.

4.3 SPECTRAL SIGNATURE IDENTIFICATION

The following methodology was used for the identification of the spectral signatures for the land cover classification project. This methodology, developed by Joyce[85] in 1978 for use with LANDSAT MSS data, was modified, where necessary, due to the improved resolution of LANDSAT TM data.

Three rectangular training sites (5x6 pixels; approximately 150x180 meters on the ground) for each land cover class, in each quandrant (140x96 pixels) of the three Applepips TM images, were preselected using the ancillary reference materials (aerial photographs and topographic maps). Training sites were identified using the landscape approach and manual image interpretation techniques. Sites were delineated based on the general criteria for each land cover class (level I, II, III class criteria). Sites were also chosen based on accessibility for ground truth verification.

Each training site was then field checked by ground observations, to verify the interpretation and to obtain additional information on the land cover condition.[86] Joyce defines land cover condition as "the particular combination of surface features that are likely to influence the reflected energy as measured by a multispectral scanner." It refers

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[85] Joyce, A.T. "Procedures for Gathering Ground Truth Information for a Supervised Approach to a Computer-Implemented Land Cover Classification of LANDSAT-Acquired MSS Data", NASA Reference Publication 1015. Washington, DC: NASA Scientific and Technical Information Office, Jan 1978.

[86] Ibid. pp. 29.

to the homogeneity or uniformity of a particular land cover and the contrasting background features or materials within the IFOV or the scanner. These factors contribute to the averaging of spectral radiances within the IFOV (30 x 30 meters for the TM) creating what are called mixed pixels.

Land cover condition also pertains to the topography of a particular site. Relief, slope, and aspect all contribute to spectral radiance values, resulting in a range of pixel DN values, rather than a fixed DN, for the same land cover type but in a different geographic location in the same image.

Therefore, the representative sample of known land cover categories was selected based on the following criteria:

(1) Training sites were homogeneous or uniform, based on the general criteria for each militarily significant land cover class of interest;

(2) Training sites were representative of the land cover conditions within the individual study areas;

(3) Training sites could be identified and delineated on the ancillary, references, the APPLEPIPS TM image, and in the field;

(4) Training sites were reasonably accessible by ground transportation means.

The identification of characteristic spectral signatures for each land cover category of interest began with the display of each TM data band (APPLEPIPS LANDS 1-5) for each

quadrant (NW, NE, SE, SW) of the three study areas using the Mapping Option subroutine. The digital data for each band were displayed using the image enchancement technique termed density slicing or thresholding. DN values were sliced or lumped together into nominal categories based on threshold values initially determined from the "natural breaks" in the frequency histogram of each data band. The spatial distribution (up to six classes) was then displayed on a high resolution color monitor by assigning a color to each nominal land cover class.

By comparing the image displayed on the monitor with aerial photographs and topographic maps of the study areas, reference points were identified on the IM image. Using these reference points and optimum threshold values, the preselected training sites representing known land cover classes were also identified.

The ARIESIPS Signature Training subroutine was then used to record the DN values for each of the thirty pixels in the three rectangular (5 x 6 pixel) training sites for each land cover class of interest. These DN values (corresponding to Level II and III land cover spectral signatures), together with the threshold DN values (corresponding to the Level I land cover spectral signatures) were used as the minima and maxima values which define the 4-dimensional classification space in the SPD classification algorithms.

The following five band spectral signatures were developed for the level I and II land cover categories in the Farmington and New Hill study areas. Due to similarities in land cover conditions, these signatures were used for the TPD classification of both images. Table 17 lists the spectral signatures developed for the two predominantly forested/agricultural areas.

Characteristic spectral signatures for only five of the six Level I land cover categories initially identified in the Farmington and New Hill study areas were clearly identifiable. These categories were: (1) Barren - includes fallow fields; roads, railroads, pipeline corridors; and other man-made surface materials. (2) Forest- Deciduous - > 60 percent of the area covered by deciduous trees; includes mixed forest. Evergreen - > 60 percent of the area covered by coniferous trees; includes mixed forest. (3) Agricultural - Crop/Pasture - includes senesced pasture cover; open areas with scattered trees (< 25 percent canopy closure); and cultivated spring wheat fields. (4) water - includes man-made lakes and farm ponds. (5) wetland - forested wetland swamp areas with predominantly deciduous tree cover.

Characteristic spectral signatures for only three of the twelve Level II land cover classes were clearly identifiable on the Farmington and New Hill images. The low density rural farm and rural non-farm urban class; transportation/communication/utilities (roads, transmission corridors, rail-

Disadvantages of the APPLEPIPS supervised nonparametric approach are: (1) the data must be reformatted to a 5 1/4 inch floppy disk which is beyond the capability of the system (in this case reformatting was accomplished by the University of Nebraska at Lincoln's Remote Sensing Center); (2) detailed ancillary references must be readily available during the analysis, classification, and accuracy assessment steps; (3) limitations of the Apple II hardware permit the color monitor display of only six land cover categories, at one time, using high resolution graphics; (4) the hard copy display (dot matrix map) of the land cover categories cannot be scaled to the topographic map of the area due to limitations in the hard copy algorithm and printing procedures of the Apple compatible dot matrix printer; and (5) the size of the APPLEPIPS TM image is restricted to 280 x 192 pixels, approximately 8.4 x 5.0 kilometers.

Advantages of the APPLEPIPS approach include: (1) the image processing system is low cost, commercially available, and compatible with microcomputer hardware systems currently fielded in the military; (2) the system is well documented and easy to learn by personnel with limited computer and image processing knowledge; and (3) providing that the TM data is in the correct format and ancillary references are available, LANDSAT digital imagery can be analyzed, classified, and land cover maps produced in a relatively short period of time (several hours), depending upon the level of expertise of the image analyst.

cant land covers using LANDSAT 4 Thematic Mapper data. This low cost, commercially available, image processing system is compatible with microcomputer hardware systems currently fielded at the corps and division level in the US Army. The decentralization of LANDSAT digital image processing to the user level would provide timely, current land cover information (derived from recently acquired LANDSAT TM data) to supplement existing topographic maps and aerial imagery. The application of Thematic Mapper data, in keeping with the all-source analysis concept, would provide a new dimension to the acquisition of tactical terrain data.

The classification system used in this study (a modified USGS land cover classification system for use with remote sensor data) provides a standard convention for the analysis and classification of tactical terrain data using LANDSAT TM digital imagery. This system permits the accurate mapping of Level I and II land cover categories using the APPLEPIPS parallelepiped classification algorithm. This supervised nonparametric method permits the complimentary application of both the landscape and quantitative approaches to terrain evaluation. Although the detailed level III land cover categories were not successfully mapped using this approach, current literature indicates that these categories may be obtained using various image enhancement techniques not addressed in this study.

Chapter V

CONCLUSIONS

This study demonstrates the potential use of microcomputer image processing techniques for obtaining tactical terrain data from LANDSAT multispectral digital imagery. Militarily significant Level I and II land cover classes were mapped for three North Carolina study areas, representing typical forest, agricultural, wetland, barren, water, and urban land cover categories in the Piedmont physiographic region. The accuracy of the land cover maps met the USGS classification accuracy standard of 85 percent at the 0.05 confidence level.

The application of LANDSAT digital imagery and computer-assisted processing techniques in the military terrain analysis process permits the acquisition of current tactical terrain data pertaining to vegetation, surface materials, surface drainage, and urban areas. These factors, along with data pertaining to surface configuration and obstacles, are essential for the completion of the terrain analysis process.

The Personal Image Processing System, designed for use with the Apple II series microcomputer, was used in this study to display, enhance, and classify militarily signifi-

TABLE 20

Piedmont Land Cover Classification Accuracy Results

FARMINGTON

Class	Number of Sample Sites	Number Misclassified
Barren	4	1
Agricultural		
Crop/Pasture	12	0
Forest		
Deciduous	33	3
Evergreen	29	1
Wetland		
Swamp	1	0
Water	14	0
Total	93	5

NEW HILL

Class	Number of Sample Sites	Number misclassified
Barren	15	1
Agricultural		
Crop/Pasture	9	0
Forest		
Deciduous	34	0
Evergreen	35	5
Water	0	0
Total	93	6

CHAPEL HILL

Class	Number of Sample Sites	Number Misclassified
Barren	6	0
Urban		
High Density	5	0
Forest		
Deciduous	25	0
Evergreen	57	6
Water	0	0
Total	93	6

permits an allowable number, X, of misclassified sites within stated confidence limits for a minimum acceptable accuracy level. For a minimum acceptable accuracy of 85 percent at the 0.05 confidence level, no more than 8 sites may be misclassified from a stratified random sample of 93 sites.

Each study area was geometrically stratified and 93 (100x100 meter) training sites were randomly located on the images, using stratified systematic unaligned sampling with coordinates from a random number table. The land cover classification was determined from the classified image and compared to the actual land cover class observed in the field and/or interpreted from the color infrared aerial photographs for sites which were inaccessible. Table 20 lists the results of the classification accuracy assessment for the Piedmont study areas.

In each case, no more than 8 sample sites were misclassified. Based on these observations, the classification accuracy of the three Piedmont study area land cover maps produced using the Apple Personal Image Processing System and LANDSAT 4 Thematic Mapper data was determined to meet the USGS accuracy standard of 85 percent at the 0.05 confidence level.

executed with an expansion of the original signatures of 100 percent for the Farrington and New Hill images. Approximately 3 percent (400 pixels per quadrant) of the Farrington and New Hill images did not fall within a land cover class during execution of the algorithm. These pixels represent primarily mixed boundary transition areas (mixed pixels) between land cover classes; swampy areas; the agricultural crop/pasture class (winter wheat); and fallow fields.

Three iterations of the PPD algorithm with an expansion of 100 percent were necessary for the Chapel Hill image resulting in approximately 4 percent (530 pixels per quadrant) of the image not being classified into one of the five land cover categories. These unclassified pixels corresponded to the high-density urban and transportation classes. Low-density urban (residential, single family dwelling with dense, tree covered lots) were classified as either deciduous or evergreen forest.

4.5 CLASSIFICATION ACCURACY ASSESSMENT

The classification accuracy of the Piedmont land cover maps produced from the LANDSAT 4 digital data was determined using an accuracy assessment technique designed by Ginevan.[87] This technique is based on a random sampling design which minimizes the number of ground truth sites, N, and

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[87] Ginevan, M.E. "Testing Land-Use Map Accuracy: Another Look", Journal of Photogrammetric Engineering and Remote Sensing, Vol.45,No.10, Oct 79, pp. 1371-1377.

TABLE 19

FPL Classification Results

Percent of Quadrant in Each Class

FARMINGTON

	NW	NE	SW	SE
Barren	1	1	<1	1
Agricultural				
Crop/pasture	6	10	3	6
Forest				
Deciduous	55	38	56	26
Evergreen	31	29	36	29
Wetland				
Swamp	0	<1	0	<1
Water	<1	15	<1	35
Unclassified	2	4	3	4

NEW HILL

	NW	NE	SW	SE
Barren	2	5	2	3
Agricultural				
Crop/Pasture	16	17	18	15
Forest				
Deciduous	47	52	45	46
Evergreen	29	19	29	32
Water	<1	<1	<1	<1
Unclassified	4	4	3	2

CHAPEL HILL

	NW	NE	SW	SE
Barren	4	3	3	2
Urban				
High Density	22	13	17	16
Forest				
Deciduous	15	15	6	14
Evergreen	52	62	59	58
Water	3	2	9	1
Unclassified	2	3	3	7

Two iterations of the FPD classification algorithm were

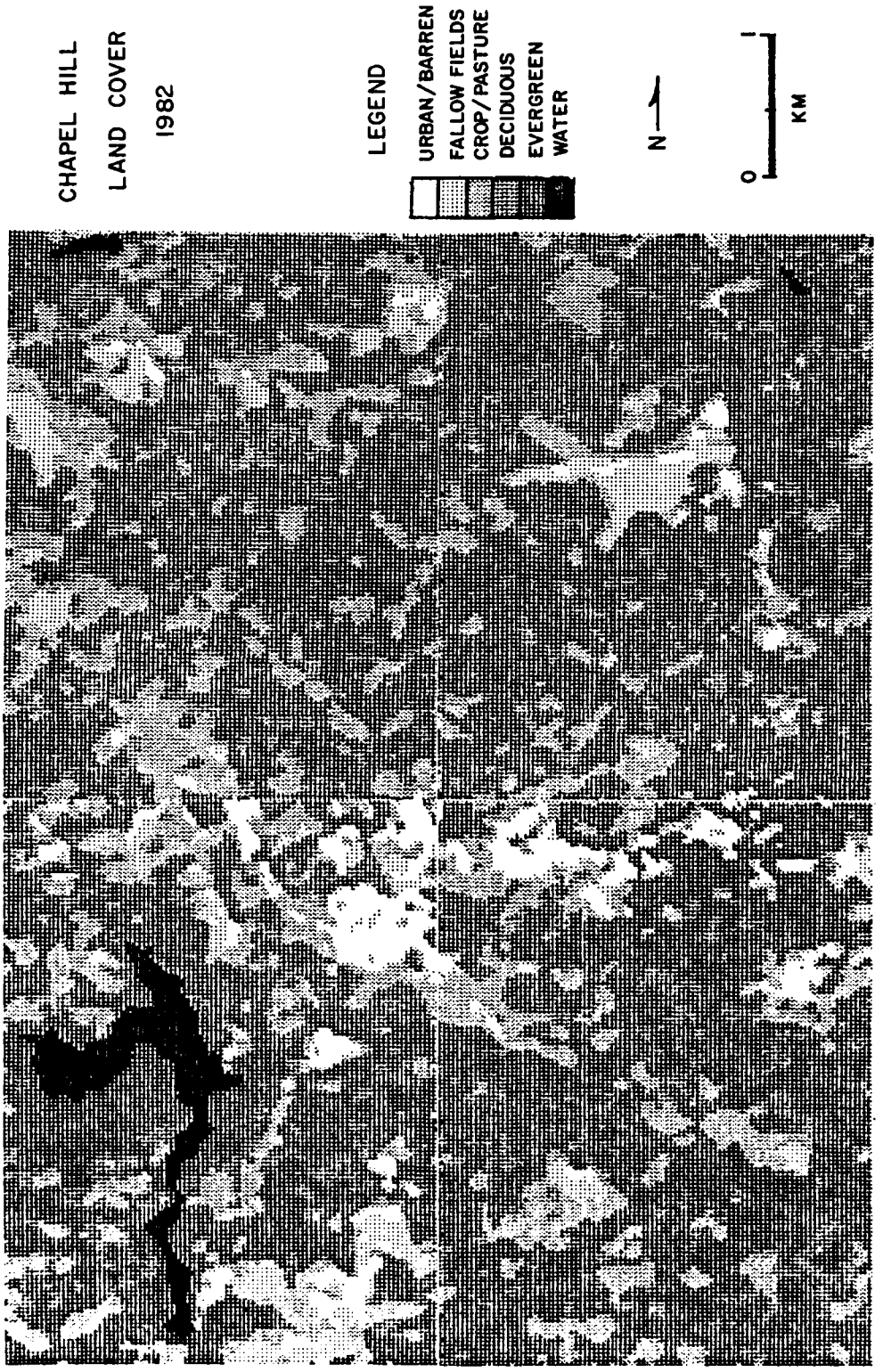

Figure 7: Chapel Hill Land Cover Map

Figure 6: New Hill Land Cover Map

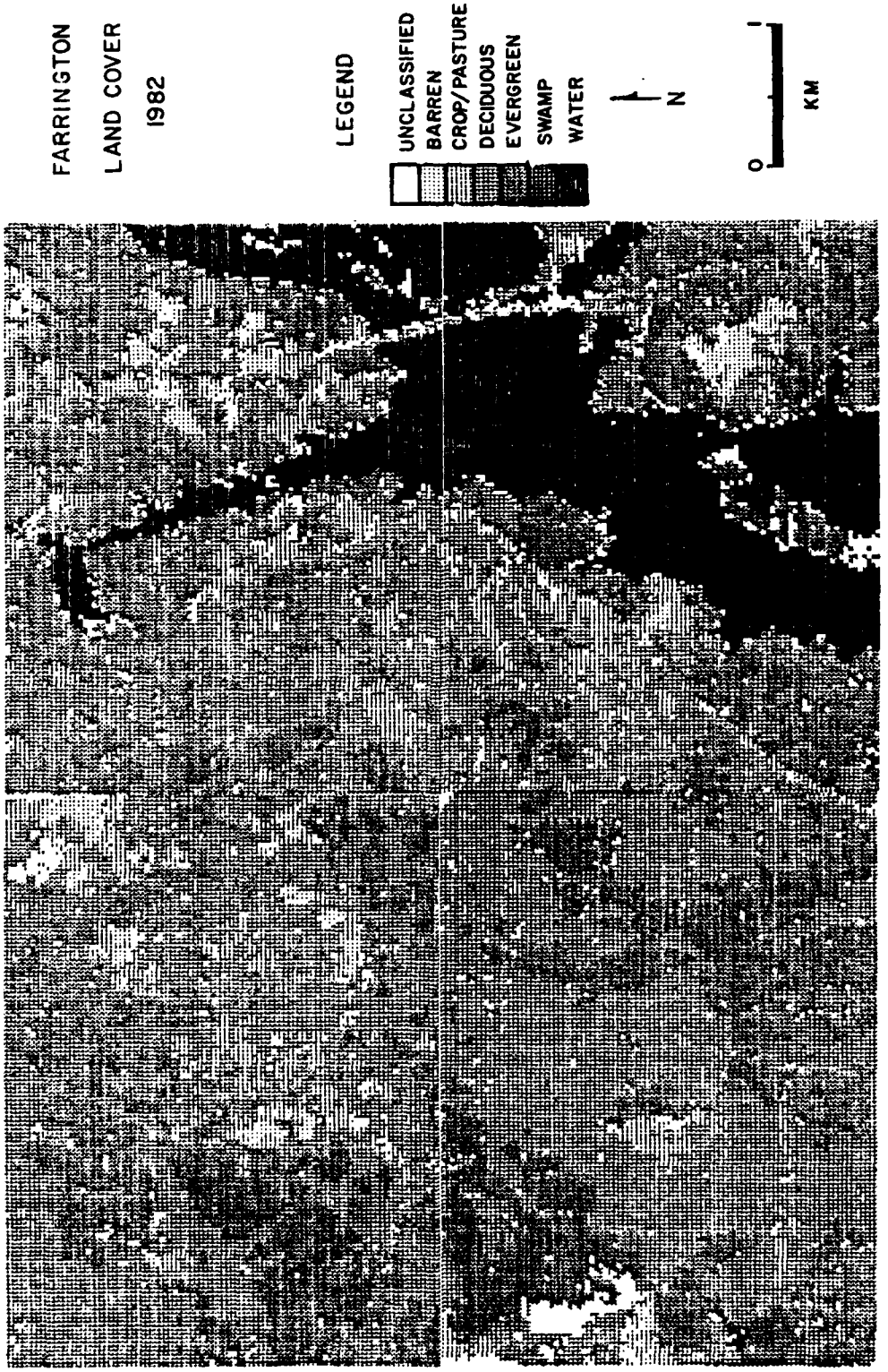

Figure 5: Farrington Land Cover Map

4.4 PPD CLASSIFICATION

Spectral bands 3, 4, and 5 (TM Bands 5, 7, and PC1) were selected for PPD classification. Spectral signatures for these three bands were better separated and more clearly defined than were those of bands 1 and 2. These bands represent the two TM middle infrared channels and the first principal component of the four original bands (TM 2, 4, 5, 7).

Figures 5 through 7 depict the level II land cover categories classified using the APPLEPIPS PPD classification algorithm.

Table 19 lists the land cover categories and percentage of the image in each category for each of the three Piedmont study areas.

Characteristic spectral signatures for the five Level I land cover categories (urban, agricultural, forest, water, barren) initially identified in the Chapel Hill study area were successfully developed using the signature development methodology previously discussed. Variations in land cover conditions and spatial distributions of similar land cover categories resulted in the development of different signatures (range of DN values) for Chapel Hill than for New Hill and Farrington.

Only two of the twelve Level II land cover categories were clearly identifiable on the Chapel Hill image (deciduous and evergreen forest). Mixed forest class spectral responses fell in either the deciduous or evergreen class depending upon the dominant tree type in each pixel. Similar spectral responses were also found for the high density urban class (areas devoid of vegetation; commercial, service, industrial, institutional, extractive areas; roof tops); the agricultural crop/pasture class (cultivated spring wheat and senesced pasture cover); and other urban land (parks, playing fields/courts, undeveloped land). Likewise, the transportation/communication/ utilities class (roads, railroads, airfield, transmission line corridors); fallow fields (barren coarse soils); and open areas (0-25 percent canopy closure) all possessed similar spectral response patterns and could not be differentiated by spectral response alone.

values. Mixed evergreen and deciduous forest were also not clearly identifiable.

Table 18 lists the five band spectral signatures developed for the predominantly urban Chapel Hill image.

TABLE 18

Level I and II Spectral Signatures Chapel Hill Area

CLASS	PIPS BAND	MIN	MAX
Urban			
High Density	1	25	66
Crop/Pasture	2	48	52
Other Urban	3	58	79
	4	18	23
	5	18	23
Forest			
Deciduous	1	20	24
	2	36	47
	3	41	57
	4	15	17
	5	15	17
Evergreen	1	20	24
	2	24	40
	3	24	40
	4	8	14
	5	8	14
Barren			
Transportation/	1	25	66
Communication/	2	53	71
Utilities	3	80	124
Fallow Fields	4	24	60
Open Areas	5	24	34
Water	1	18	19
	2	0	23
	3	0	23
	4	0	7
	5	0	7

TABLE 17

Farrington and New Hill Spectral Signatures

CLASS	PIPS BAND	MIN	MAX
Barren	1	35	51
	2	50	71
	3	78	117
	4	39	66
	5	26	38
Agricultural Crop/Pasture	1	24	34
	2	43	49
	3	65	77
	4	24	38
	5	21	25
Forest Deciduous	1	20	25
	2	37	42
	3	47	64
	4	15	23
	5	15	20
Evergreen	1	20	25
	2	29	36
	3	28	46
	4	10	14
	5	9	14
Wetland Swamp	1	19	19
	2	14	28
	3	11	27
	4	7	9
	5	8	8
Water	1	16	18
	2	7	13
	3	2	10
	4	0	6
	5	0	7

roads); and fallow, barren crop fields (coarse and fine grained soils), had very similar, indistinguishable spectral responses in all bands. Similarly, deep and shallow water and nonforested wetland (marsh) were in the same range of DN

Although aerial photography remains the basic tool for the acquisition of tactical terrain data, the application of LANDSAT digital imagery and microcomputer-assisted processing techniques (in the data acquisition and classification step of the military terrain analysis process) provide an additional source of information pertaining to the environmental conditions of a specific area of operation. Completion of the terrain analysis process, using accurate, up-to-date tactical terrain data, provides essential information that commanders need to make tactical decisons that ultimately determine the successful execution of military operations.

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